RESEARCH & DEVELOPMENT

North Carolina Highway Cost Allocation and Revenue Attribution Study

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16. Abstract

The objective of this research is to estimate and compare the highway infrastructure cost responsibility and revenue contribution of highway users in North Carolina. The study adopted the FHWA 13 vehicle classification system and analyzed data on highway infrastructure expenditures and federal and state revenue for the years 2014-2017.

The results of this research indicate that lightweight vehicles, including motorcycles and passenger cars, contribute more to the revenue than their share of cost responsibility. Specifically, it was found that motorcycles, passenger cars, and FHWA class 3 vehicles overpay by 30%, 26%, and 8%, respectively. On the other hand, single-unit trucks with four or more axles (FHWA class 7) and all multi-unit trucks classes (FHWA classes 8-13) underpay by 37%-92% for highway infrastructure compared to the damage they cause. In summary, lightweight vehicles are currently subsidizing the cost responsibility of most trucks on North Carolina's highway system.

The results of this study reveal that NCDOT should explore ways to increase the share of revenue contributions from trucks to improve equity in revenue generation. Several revenue scenarios were analyzed as part of this study, such as increasing the rates of current sources of revenue as well as investigating new sources, such as mileage-based user fees and dedicating state sales tax revenue to transportation. Although most of the revenue scenarios explored as part of this research are implementable and reasonable when compared to the tax and fee structures in other states, none of these scenarios was found to lead to substantial equity improvements. Future research should focus on a detailed exploration of tax and fee structures that can significantly enhance equity in NC's transportation infrastructure revenue generation process.

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1 Introduction

1.1 Background

North Carolina (NC) finances highway infrastructure mainly with the motor fuels tax, highway use tax, and motor vehicle fees. Highway users contribute to these revenue sources based on either how much they use the infrastructure or the transportation mode that they own. Ideally, each highway user contributes to the revenue an amount equal to the cost of consuming the state's infrastructure. However, this is challenging to achieve in practice, and in the majority of states, users of lighter vehicles overpay for highway infrastructure. To enable policymakers to plan and implement more equitable tax and fee systems, it is necessary to periodically assess the cost responsibility of highway users and compare it with their contribution to the revenue.

To date, no study of highway cost allocation and revenue attribution has been completed for NC. It is therefore not clear whether certain highway users overpay or underpay for highway infrastructure. This hinders the North Carolina Department of Transportation (NCDOT) from exploring more equitable mechanisms for collecting revenue and funding future infrastructure projects. In addition, due to the continuous improvements in vehicle fuel efficiency and the increasing market penetration of electric vehicles, traditional revenue sources such as the gas tax will be unable to provide sustainable revenue for funding highway infrastructure in the near future. Thus, identifying alternative funding mechanisms that are equitable but can also sustain revenue has become a pressing need.

1.2 Scope of the Study

The objective of this research is to estimate and compare the cost responsibility and revenue contribution of individual vehicle classes for North Carolina's highway infrastructure. This comparison is based on highway infrastructure expenditures and federal and state revenue sources between 2014 and 2017. The study also includes an analysis of future revenue scenarios and assesses alternative infrastructure funding mechanisms and evaluates them based on revenue potential, financial sustainability, ease of implementation, and public perception. As the federal government and other states evaluate innovative policies to secure the financial sustainability of highway infrastructure, this study is paramount to ensure NCDOT and the state legislature can make informed decisions in the near future.

2 Review of Highway Cost Allocation Studies from Different States

2.1 Study Methodologies/Model Used

There are several approaches for estimating highway user costs. A number of states across the United States (US) have adopted different approaches to estimate the user costs and attribute the revenue shares. A majority of the state highway cost allocation studies adopted either the incremental method or the federal method (P Balducci et al., 2009). Collectively these two methods fall under the cost-occasioned approach. In the cost occasioned method, cost responsibilities are determined based on the costs occasioned by various highway user classes (P Balducci et al., 2009), and each class of road user should pay for the system of roads in proportion to the costs associated with road use by that class (ECONorthwest, 2019). Most of the recent studies employ the incremental method to allocate costs among different highway users. In this method, aspects of highway costs are divided into increments and only the responsible users (i.e. specific vehicle classes) are charged for the costs of successive increments (ECONorthwest, 2019). For instance, a design sufficient to hold the light vehicle classes is the common responsibility of all highway users and is shared by all vehicle classes. As the design requirement and investment increase for accommodating the heavier vehicle classes, the cost is shared accordingly among the heavier vehicle classes. Besides the cost-occasioned approach, a Texas highway cost allocation study (HCAS) applied four other approaches and compared the results with the Federal Highway Administration's (FHWA) incremental approach (Luskin et al., 2002). Oregon's HCAS described a "benefit approach" of cost allocation as an alternative to cost-occasioned approach, where the cost is allocated according to the benefits received by the users and non-users of the highway system (ECONorthwest, 2019). However, due to some major limitations, such as difficulties in measuring the benefits and varying level of benefits from similar user groups, this approach has not been applied in any state HCAS.

To help the states in highway cost allocation analyses, FHWA developed a HCAS tool in 1997 (FHWA, 1997). States have either used this tool or developed state-specific tools for their highway cost allocation analysis. For instance, Oregon used ODOT's Cash Flow Forecast model in their 2017-2019 biennium study (ECONorthwest, 2019). Nevada and Idaho modified the FHWA HCAS tool to meet their state-specific characteristics (Balducci et al., 2010; P Balducci et al., 2009), and Minnesota developed their own model, the Minnesota Highway Cost Allocation Tool (MHCAT) (Gupta and Chen, 2012).

To review highway cost allocation for NC, this study followed the original FHWA HCAS tool (FHWA, 1997). The tool includes elaborate procedures to allocate the costs of new pavements and bridges as well as pavement and bridge rehabilitation costs. Brief discussions on the methodologies are included in this report under the specific analysis sections.

2.2 Vehicle Classification

FHWA has a standardized vehicle classification system that divides all vehicles into 13 categories. Figure 2.1 illustrates the different vehicle classes as categorized by FHWA, and Table 2.1 presents the short vehicle class names and description.

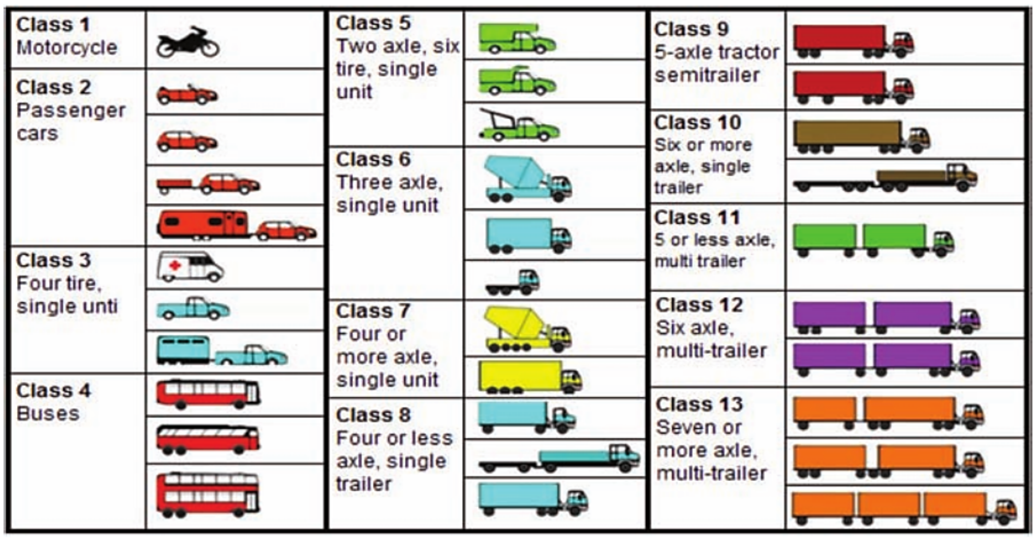


Figure 2.1: FHWA vehicle classification (Source: FHWA, 2017a).

Table 2.1: FHWA vehicle classification.

FHWA vehicle class	Name	Description
1	MC	Motorcycle
2	Cars	Passenger car
3	2A4T	Four tire single unit
4	Bus	Bus
5	2ASU	Two axle, six tire, single unit
6	3ASU	Three axle, single unit
7	4ASU	Four or more axle, single unit
8	4AST	Four or less axle, single trailer
9	5AST	5-axle tractor semitrailer
10	6AST	Six or more axle, single trailer
11	5AMT	Five or more axle, multi-trailer
12	6AMT	Six axle, multi-trailer
13	7AMT	Seven or more axle, multi-trailer

While some states, such as Indiana (Volovski et al., 2015), have adopted the FHWA recommended classification, many other states use different methods to classify their vehicle fleet into different categories based on criteria like weight, size, and other factors. Table 2.2 shows the vehicle classification used in different states.

Table 2.2: Vehicle classification system used in HCAS studies of different states.

State	Vehicle classification system
Oregon (ECONorthwest, 2019)	Oregon used seven summary-level gross weight groups: 1) 1 to 10,000 pounds (light vehicles) 2) 10,001 to 26,000 pounds (medium-heavy vehicles) 3) 26,001 to 48,000 pounds 4) 78,001 to 80,000 pounds 5) 80,001 to 104,000 pounds 6) 104,001 to 105,500 pounds 7) Over 105,500 pounds
Nevada (P Balducci et al., 2009)	Nevada used 11 vehicle classes in their HCAS model: 1) Auto: Automobiles, vans, light trucks with 2-axles and 4 tires and motorcycles 2) Bus: Buses (all larger types) 3) SU2: Single unit 2-axle, 6-tire trucks 4) SU3+: Single unit trucks with 3 or more axles 5) CB3&4: Combination trucks with 3 or 4 axles 6) CB5: Combination trucks with 5 axles 7) CB6+: Combination trucks with 6 or more axles 8) DS5: Tractor-double semitrailer combinations with 5 axles 9) DS6: Tractor-double semitrailer combinations with 6 axles 10) DS7+: Tractor-double semitrailer combinations with 7 or more axles 11) TRPL: Tractor-triple semitrailer
Texas (Luskin et al., 2002)	Texas divided their vehicle fleet into 12 different classes: 1) Auto: Automobiles (also termed “passenger cars”) 2) Pickup: Single-unit trucks with 2 axles and 4 tires 3) Other 2 Ax SU: Single-unit trucks with 2 axles and6 tires 4) 3 Ax SU: Single-unit trucks with 3 axles 5) 4 Ax+ SU: Single-unit trucks with 4 or more axles 6) 4 Ax– STT: Combination trucks with single trailer and 4 or fewer axles 7) 5 Ax STT: Combination trucks with single trailer and 5 axles 8) 6 Ax+ STT: Combination trucks with single trailer and 6 or more axles combination 9) 5 Ax– MTT: Combination trucks with multiple trailers and 5 or fewer axles 10) 6 Ax MTT: Combination trucks with multiple trailers and 6 axles 11) 7 Ax+ MTT: Combination trucks with multiple trailers and 7 or more axles 12) Bus

Idaho (Balducci et al., 2010)	This study used 20 vehicle classes, similar to the FHWA HCAS tool (FHWA, 1997). These vehicle classes range from automobiles to tractor-triple semitrailer or tractor-double trailer combinations. Vehicle classes are further differentiated based on weight up to 130,000 pounds RGW in 2,000-pound increments above 8,000 pounds.
Minnesota (Gupta and Chen, 2012)	The Minnesota HCAS tool is developed for 20 vehicle class system, similar to the FHWA HCAS tool (FHWA, 1997). But the user can choose either Highway Performance Monitoring System's (HPMS) 12-vehicle classes or 20-vehicle classes. All calculations for Minnesota HCAS are based on the 20-vehicle classes. If the user chooses to use HPMS 12-vehicle class system, then it will be mapped onto 20-vehicle class system used by HCASP.

2.3 Road System

The FHWA functional classification system groups each roadway into different classes based on the character of travel service they provide (FHWA, 2017). The classification tree described in FHWA is given in Figure 2.2.

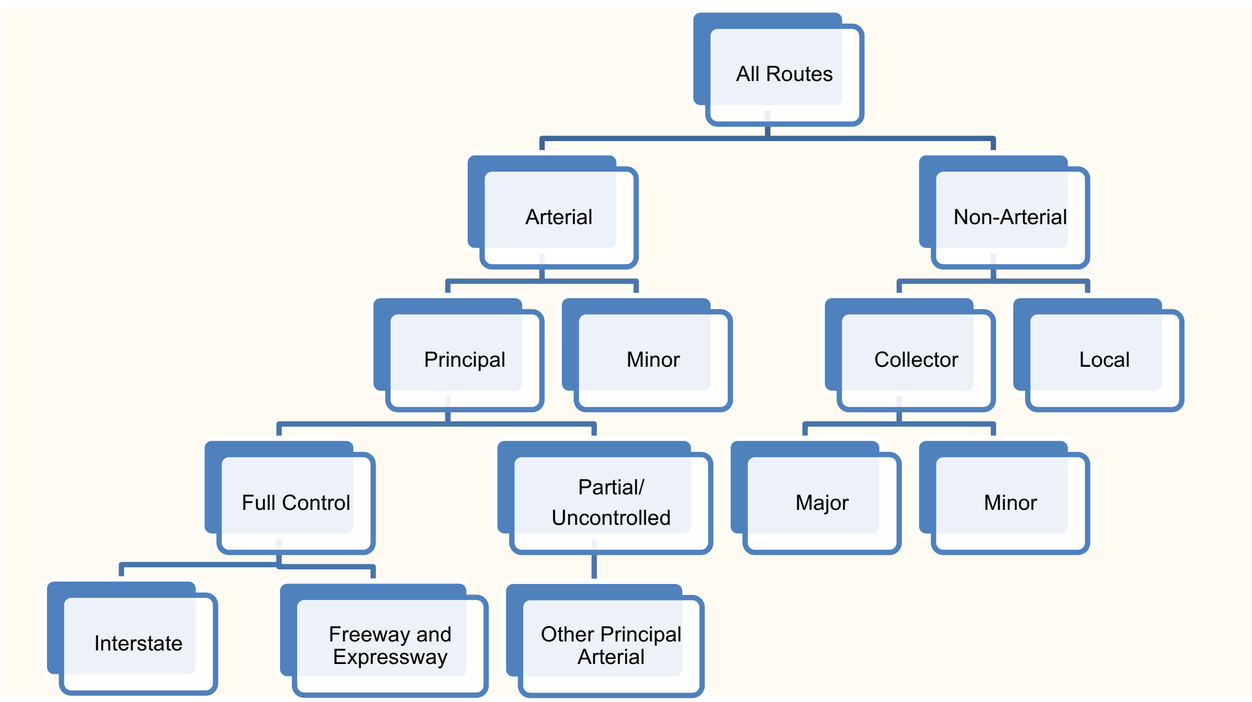


Figure 2.2: FHWA functional classification of roadway (Source: FHWA, 2017b).

Most of the state level highway cost allocation studies, including Oregon, Nevada, Idaho, Indiana, Minnesota, and Nevada, used the FHWA recommended functional roadway classification. The twelve major road classes in these studies were:

1) Rural Interstate
2) Rural Other Principal Arterials
3) Rural Minor Arterials
4) Rural Major Collectors
5) Rural Minor Collectors
6) Rural Local
7) Urban Interstate
8) Urban Other Freeways and Expressways
9) Urban Other Principal Arterials
10) Urban Minor Arterials
11) Urban Collectors
12) Urban-Local

Texas used the same classification, excluding the local roads, and classified the flexible pavements differently to collect the initial serviceability index data (Luskin et al., 2002).

2.4 Expenditure Types and Key Allocators

State highway funds are used in roadway development, management, and improvement works in different types of facilities. Not all of these expenditures are directly associated with highway management; thereby, not all of these expenditures are considered while allocating the costs among different user groups. Table 2.3 summarizes the expenditure fields included in recent HCASs completed by different states.

Table 2.3: Types of expenditure/costs included in recent HCAS studies of different states.

Oregon (ECONorthwest, 2019)	▪ Modernization: Installing additional lanes, straightening curves, and replacing bridges with more lanes. ▪ Preservation: Resurfacing and rehabilitation works. ▪ Maintenance and Operations: Maintenance work such as patching potholes, pavement striping, snow and ice removal, and bridge maintenance. Operations include installing and maintaining traffic signals, signage, and lighting. ▪ Administration, Collection, Planning and Other Costs This study excluded indirect or external costs such as those associated with congestion, pollution, noise, and the societal costs of traffic accidents.
Indiana (Volovski et al., 2015)	▪ Pavement expenditure: Expenditures on new pavement construction, pavement rehabilitation, and in-house maintenance works, including grading and earthwork, shoulder construction, right-of-way purchase, drainage, and erosion control, and miscellaneous. ▪ Bridge expenditure: Expenditures on new bridge construction, bridge rehabilitation, and bridge replacement work. ▪ Safety, mobility, and other expenditures
Minnesota (Gupta and Chen, 2012)	▪ Pavement-related expenditures: New pavement construction, and pavement repair works.

	▪ Bridge-related expenditures: New bridge construction, replacement and repair work. ▪ Expenditures on grading and drainage related works. ▪ Transit and rail related expenditures from highway funds. ▪ Truck related expenditures: Construction and maintenance of weigh station, escape ramp, and other truck-specific infrastructures. ▪ Miscellaneous: Operation and safety related expenses and maintenance of rest areas.
Idaho (Balducci et al., 2010)	▪ Capital highway projects: Federal, state, and local expenditures, including new pavement, pavement rehabilitation, new bridge, bridge replacement and repair, grading, safety, environment, other construction, and maintenance work. ▪ Non-capital expenditures: Expenses in Division of Motor Vehicles (DMV), administration, construction, and maintenance of capital facilities (e.g., Idaho Transportation Department buildings), highway operations and maintenance, public transportation, Idaho State Police, and planning activities.
Nevada (P Balducci et al., 2009)	▪ Construction of new pavement and bridge structures. ▪ Rehabilitation and replacement of bridges. ▪ Maintenance of pavement and bridge structures: Travel related, wear related, and load related maintenance for flexible and rigid pavements and bridges. ▪ Expenditures from federal stimulus. ▪ Administrative and other costs to run the Department of Motor Vehicles (DMV) ▪ Expenditures by the Department of Public Safety (DPS) to cover the costs of various activities in response to highway incidents such as cleanup efforts, police direction, emergency responses and property damages.

Cost allocators are the measures used to allocate the expenditures to different vehicle classes. The key allocators used in different HCASs include (P Balducci et al., 2009):

- Travel-related allocators: Vehicle miles traveled (VMT)
- Allocators related to the space taken by vehicles: Passenger car equivalents (PCE)
- Load-related allocators: Equivalent single axle loads (ESALs), gross vehicle weight
- Combination of these measures: ESAL-miles, ton-miles, axle-miles, and PCE-miles.

The use of allocators varied based on the type of infrastructure (e.g., pavement or bridge) and the type of project (i.e., new construction, rehabilitation, repair, or maintenance).

The total costs from expenditure fields are allocated among the user groups (vehicle classes) based on different allocation factors. In most of the state HCASs, the expenditures are divided into two major categories: common costs (which are shared equally by all the user groups) and construction and major rehabilitation costs, which largely depend on the weights and axle distributions of the vehicles. Common costs include rest areas, roadside mowing and cleanup, provision and maintenance of traffic signs and signals, maintenance required as the result of rockslides, floods, and other weather-related events, and general administrative costs. These are allocated based on VMT by each vehicle class (Balducci et al., 2010; P Balducci et al., 2009; ECONorthwest, 2019; Sinha et al., 1984). The second types of cost include design, construction, rehabilitation, and maintenance of pavements, bridge, ramps, and other roadway infrastructure. These costs are allocated based on vehicle's size, gross weight, axle weight and other load-related and/or combined characteristics (Balducci et al., 2010; P Balducci et al., 2009; ECONorthwest, 2019; Sinha et al., 1984).

2.5 Major Findings of Previous Studies

The various states' HCAS reports focused mainly on one broad question: whether a certain vehicle class is paying its share of cost responsibility to the state's revenue. The majority of past studies have answered this question by calculating the equity ratio, which is the ratio of attributed revenue and the cost responsibility of each vehicle class. Table 2.4 summarizes the major findings from several states' recent studies.

Table 2.4: Major findings from recent HCAS studies of different states.

State	Findings
Oregon 2017-19 (ECONorthwest, 2019)	Light vehicles (declared weights up to 10,000 lbs) and heavy vehicles (declared weights above 10,000 lbs) had an average equity ratio of 1.0078 and 0.9865, respectively. In other words, the light vehicles overpay by 0.76% and the heavy vehicles underpay by 1.35%. Notably, among the heavy vehicles, those with declared weight between 80,001-104,000 lbs, 104,001-150,500 lbs, and above 150,500 lbs were found to underpay by 24.87%, 27.81%, and 66.87%, respectively.
Nevada (P Balducci et al., 2009)	Considering all levels of government (federal, state, and local), the adjusted equity ratio for passenger vehicles was found to be 1.43, meaning they overpaid by 43% of their cost responsibilities. Adjusted equity ratios for trucks were between 0.27 to 0.82. Among the trucks tractor-triple semitrailer or truck-double

	semitrailer combinations (TRPL) underpaid by 73% whereas single unit trucks with three or more axles underpaid by 18%. For state-level cost responsibility and revenue analysis, the adjusted equity ratio for passenger vehicles and TRPL were reported to be 1.57 and 0.20, respectively. Thus, at the state level, passenger vehicles overpaid by 57% while TRPL underpaid by 80%.
Texas (Luskin et al., 2002)	The study reported the findings from four different cost allocation methods: generalized method, modified incremental approach, proportional method (using ESALs), and FHWA approach. Passenger vehicles and pickup trucks were found to overpay between 15-34% and 35-73%, respectively. Other single-unit trucks were reported to underpay between 5-20%. Combination trucks were found to underpay between 35-49%.
Indiana (Volovski et al., 2015)	Indiana HCAS used the FHWA 13 vehicle classification system. User equity ratio suggested that motorcycle, passenger vehicles, 4-tire single unit trucks, and buses overpaid by 12%, 10%, 16%, and 3%, respectively. Among the other single unit trucks, class 7 (4 or more axle single-unit trucks) had the lowest equity ratio with 0.67, meaning it underpaid by 33%. Among the multi-unit trucks, class 10 (6 or more axle single trailer trucks) had the lowest equity ratio with 0.75, meaning it underpaid by 25%.
Idaho (Balducci et al., 2010)	At the state level, passenger vehicles, pickups, buses, and single-unit trucks overpaid by 26%, 5%, 39%, and 36%, respectively. Considering both state and federal costs and revenues, passenger vehicles, pickups, and buses overpaid by 47%, 18%, and 6%, respectively, while the single-unit trucks underpaid by 2%. Combination trucks underpaid between 27% to 33%.
Minnesota (Gupta, 2012)	The Minnesota highway cost allocation used two approaches: the FHWA HCAS tool and the Minnesota Highway Cost Allocation Tool (MHCAT). Results from MHCAT suggested that passenger cars, light trucks, 2-axle 4-tire single unit trucks, 3 or more axle single unit trucks, and combination trucks with 3 or 4 axles overpaid by 18%, 6%, 44%, 19%, and 9%, respectively. Other combination trucks and the buses were found to underpay by 22-68% and 15%, respectively. Analysis from the FHWA HCAS tool provided similar results except for combinations trucks with 3 or 4 axles (CB34). According to the FHWA tool, CB34 overpaid by 13%, whereas according to MHCAT CB34 overpaid by 9%.

Table 2.5 presents the unit travel costs ($ per mile) for four recent HCASs (Indiana, Minnesota, Nevada, and Idaho).

Table 2.5: Unit travel costs from in recent HCASs completed in different states.

Indiana (Volovski et al., 2015)		Minnesota (Gupta and Chen, 2012)		Nevada (P Balducci et al., 2009)		Idaho (Balducci et al., 2010)	
Vehicle	Cost ($/VMT)	Vehicle	Cost ($/VMT)	Vehicle	Cost ($/VMT)	Vehicle	Cost ($/VMT)
MC	0.026	_	_	_	_	_	_
Cars	0.026	Cars	0.015	Cars	0.022	Cars	0.038
2A4T	0.028	2A4T	0.019	_N.A	__	2A4T	0.047
Bus	0.129	Bus	0.065	Bus	0.245	Bus	0.121
2ASU	0.06	2ASU	0.040	2ASU	0.097	2ASU	0.104
3ASU	0.191	3ASU	0.079	3ASU	0.223	3ASU	0.223
4ASU	0.713	4ASU	0.162	N.A._	__	4ASU	0.289
4AST	0.189	4AST	0.074	4AST	0.161	CS3	0.116
5AST	0.39	5AST	0.156	5AST	0.348	CS4	0.131
6AST	0.471	6AST	0.253	6AST	0.383	CS5T	0.247
5AMT	0.386	5AMT	0.112	5AMT	0.522	CS5S	0.271
6AMT	0.711	6AMT	0.179	6AMT	0.376	CS6	0.253
7AMT	0.993	7AMT	0.373	7AMT	0.601	CS7+	0.373
				TRPL	0.590	CT34	0.156
						CT5	0.269
						CT6+	0.574
						5AMT	0.154
						6AMT	0.167
						DS7	0.486
						DS8+	0.386
						TRPL	0.196

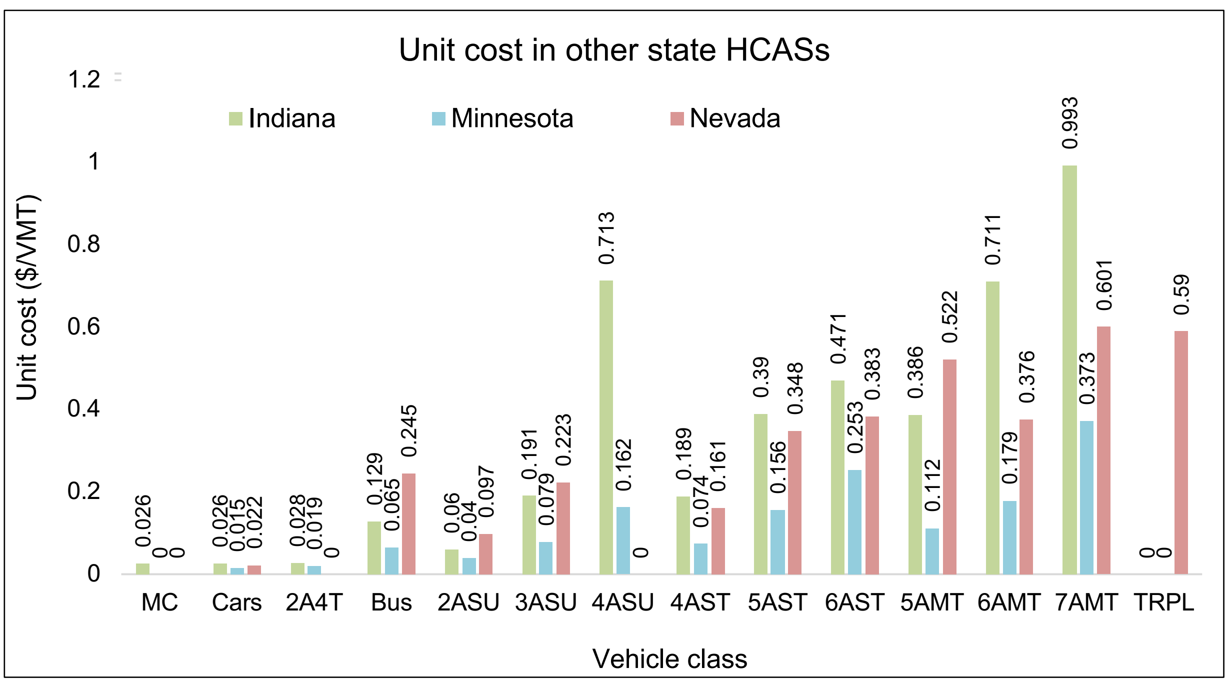


Figure 2.3: Unit cost ($/VMT) in other state highway coast allocation studies.

Figure 2.3 shows the cost responsibilities in $/VMT reported in HCASs of Indiana, Minnesota, and Nevada. Unit cost of $0/VMT indicates that vehicle class was not used in the state HCAS. Table 2.6 and Figure 2.4 show the percentage share of total cost by vehicle class reported in the state HCAS of Indiana, Minnesota, and Nevada.

Table 2.6: Percentage share of total cost by vehicle class from other states highway cost allocation studies.

Indiana (Volovski et al., 2015):		Minnesota (Gupta and Chen, 2012)		Nevada (P Balducci et al., 2009)		Idaho (Balducci et al., 2010)	
Vehicle	% Cost Responsibility	Vehicle	% Cost Responsibility	Vehicle	% Cost Responsibility	Vehicle	% Cost Responsibility
MC	0.38	_		_		_	_
Auto	43.12	Auto	38.76	Auto	55.30	Auto	22.38
LT4s	17.77	LT4	23.83	_	0.00	LT4	21.90
Bus	0.37	BUS	0.71	Bus	2.97	Bus	0.63
SU2	3.34	SU2	3.65	SU2	4.77	SU2	7.28
SU3	3.33	SU3	2.21	SU3+	2.30	SU3	4.07
SU4	3.56	SU4+	1.37	_	0.00	SU4+	0.23
CB3&4	1.72	CB3&4	1.13	CB3&4	1.50	CS3	1.07
CB5	25.16	CB5	20.89	CB5	23.48	CS4	1.69
CB6+	0.49	CB6+	6.84	CB6+	0.87	CS5T	21.89
DS5	0.33	DS5	0.26	DS5	2.85	CS5S	2.57
DS6	0.14	DS6	0.09	DS6	0.89	CS6	3.39
DS7+	0.29	DS7+	0.26	DS7+	3.01	CS7+	3.50
				TRPL	2.07	CT34	2.07
						CT5	0.08
						CT6+	0.12
						DS5	0.22
						DS6	0.37
						DS7	6.65
						DS8+	1.15
						TRPL	0.72

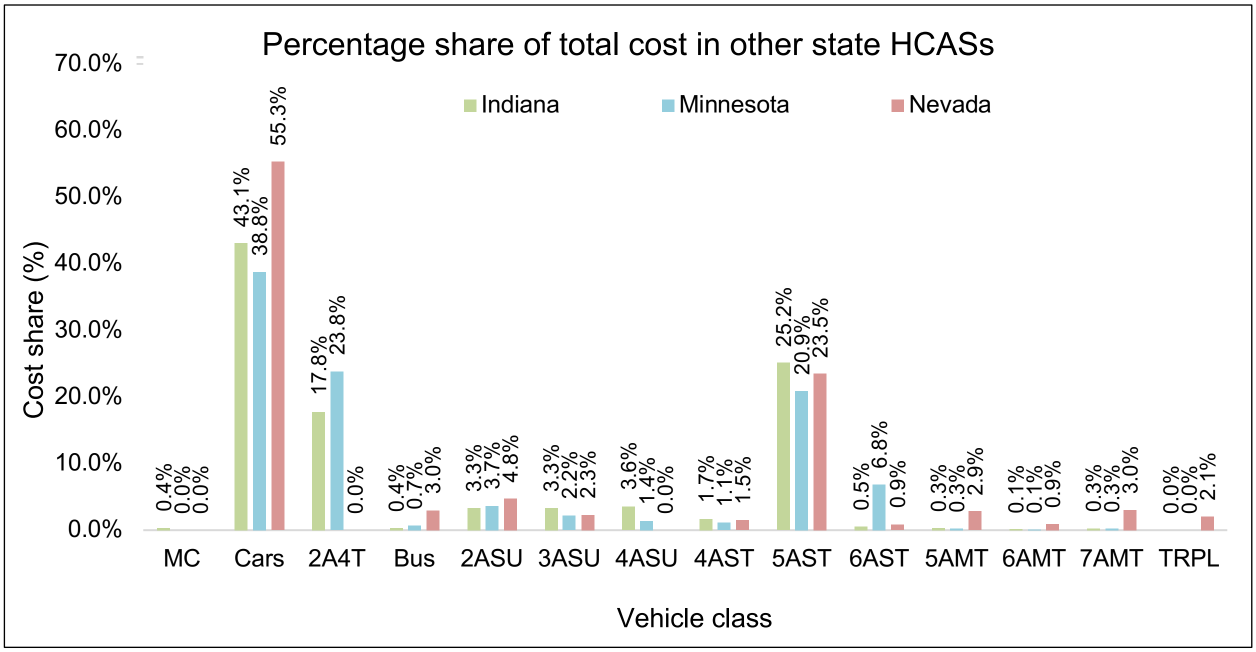


Figure 2.4: Percentage share of total costs in other state highway cost allocation studies.

In all the three state studies, FHWA class 2 vehicle or passenger cars had the highest percentage share of total cost. However, passenger cars had the lowest unit cost as they had the largest share of VMT. On the other hand, multi-unit trucks, including FHWA vehicle classes 11-13, had lower percentage share of total costs but higher unit costs. This result implies that these vehicle classes are responsible for more damage per mile of travel compared to other vehicle classes. The 0% cost share in Figure 2.4 indicates that the vehicle class was not used in the state HCAS.

3 Assessment of Highway System Usage

Highway system usage is measured in terms of VMT based on the 13 FHWA vehicle classes. NCDOT reports the annual VMTs to the FHWA highway performance monitoring system (HPMS) using the FHWA functional classifications of roadways shown in Table 3.1 (FHWA, 2013).

Table 3.1: FHWA functional classification of roadways.

Urban/Rural	FC Code	Functional Class
Urban	1	Interstate
Urban	2	PA - Other Freeways and Expressways
Urban	3	PA - Other
Urban	4	Minor Arterial
Urban	5	Major Collector
Urban	6	Minor Collector
Urban	7	Local
Rural	1	Interstate
Rural	2	PA - Other Freeways and Expressways
Rural	3	PA - Other
Rural	4	Minor Arterial
Rural	5	Major Collector
Rural	6	Minor Collector
Rural	7	Local

Each year, NCDOT publishes traffic segment data that includes the annual VMTs by route segment as reported to FHWA. NCDOT uses event data collected on more than 30,000 traffic segments to report annual average daily traffic (AADT) for all non-local routes. For local routes, NCDOT provides supplemental AADTs on more than 16,000 traffic segments. To divide the AADT into different vehicle classes, NCDOT uses vehicle class (VC) data collected from more than 3,000 VC stations which covers national highway system (NHS) and NC truck networks. For the remaining traffic segments, NCDOT uses disaggregation factors to distribute the total AADT into different vehicle classes. Table 3.2 shows the reported annual VMT on different urban and rural roadways for 2014. The total annual VMT from 2014 to 2017 by vehicle class are given in Table 3.3 and Figure 3.1.

Table 3.2: Annual VMT (in millions) for 13 vehicle classes by area and functional class in NC in 2014.

Urban/ Rural	FC	MC	Cars	2A4T	Bus	2ASU	3ASU	4ASU	4AST	5AST	6AST	5AMT	6AMT	7AMT	Total
Urban	1	73.3	13019.2	2697.7	86.0	322.0	99.5	4.9	92.4	1019.6	12.9	21.3	9.7	2.3	17460.7
	2	29.2	4067.2	959.3	28.6	118.4	32.5	3.3	44.4	206.4	6.6	5.5	2.0	1.0	5504.4
	3	74.1	11303.7	2376.7	73.8	294.1	78.9	12.6	75.7	206.0	19.9	3.8	1.5	4.1	14524.9
	4	75.9	10196.6	2321.3	60.0	286.9	63.3	9.1	64.6	121.2	14.6	1.1	0.7	3.7	13218.9
	5	34.4	5065.7	1217.4	31.0	144.5	37.1	3.1	33.4	55.8	6.9	0.1	0.1	1.4	6630.8
	6	2.9	434.2	104.3	2.7	12.4	3.2	0.3	2.9	4.8	0.6	0.0	0.0	0.1	568.4
	7	146.4	9725.2	2678.3	134.4	400.8	175.9	3.8	74.0	205.4	7.6	0.0	2.3	0.8	13554.7
Rural	1	22.4	3961.5	824.6	32.8	118.4	35.1	1.8	56.0	616.5	9.8	10.8	4.9	1.1	5695.9
	2	15.4	1565.1	435.5	13.8	61.1	14.8	1.6	22.1	95.9	3.8	1.2	0.6	0.6	2231.6
	3	37.1	3770.3	1049.2	33.3	147.2	35.7	3.8	53.2	230.9	9.2	3.0	1.6	1.5	5375.9
	4	42.3	3937.5	1143.2	30.5	156.0	31.1	3.0	47.2	174.2	8.3	0.3	0.2	1.5	5575.3
	5	56.2	4592.5	1484.5	42.3	201.6	45.3	4.0	60.0	214.6	8.8	0.2	0.1	1.0	6710.8
	6	15.5	1804.2	701.0	15.3	84.0	19.2	0.9	22.7	84.8	3.7	0.0	0.0	0.2	2751.5
	7	70.5	5912.1	1685.3	74.2	288.7	84.9	8.1	45.4	57.0	9.2	0.4	0.0	0.4	8236.3

Table 3.3: NC VMT (in millions) by year.

FHWA Class	1	2	3	4	5	6	7	8	9	10	11	12	13	Total Annual
Year	**MC**	**Cars**	**2A4T**	**Bus**	**2ASU**	**3ASU**	**4ASU**	**4AST**	**5AST**	**6AST**	**5AMT**	**6AMT**	**7AMT**	
2014	695.5	79,355.0	19,678.2	658.6	2,636.2	756.5	60.3	694.0	3,293.0	122.0	47.6	23.6	19.6	108,040.0
2015	667.5	82,600.2	19,948.4	775.8	2,695.1	737.9	66.5	719.1	3,382.8	164.0	55.3	24.5	35.5	111,872.5
2016	688.5	86,003.8	20,733.8	811.6	2,806.9	771.1	69.4	750.8	3,510.4	169.3	58.7	26.2	36.9	116,437.2
2017	685.9	87,124.9	21,736.6	865.3	2,991.3	803.9	73.6	824.3	3,708.3	163.8	59.9	25.9	40.4	119,103.9

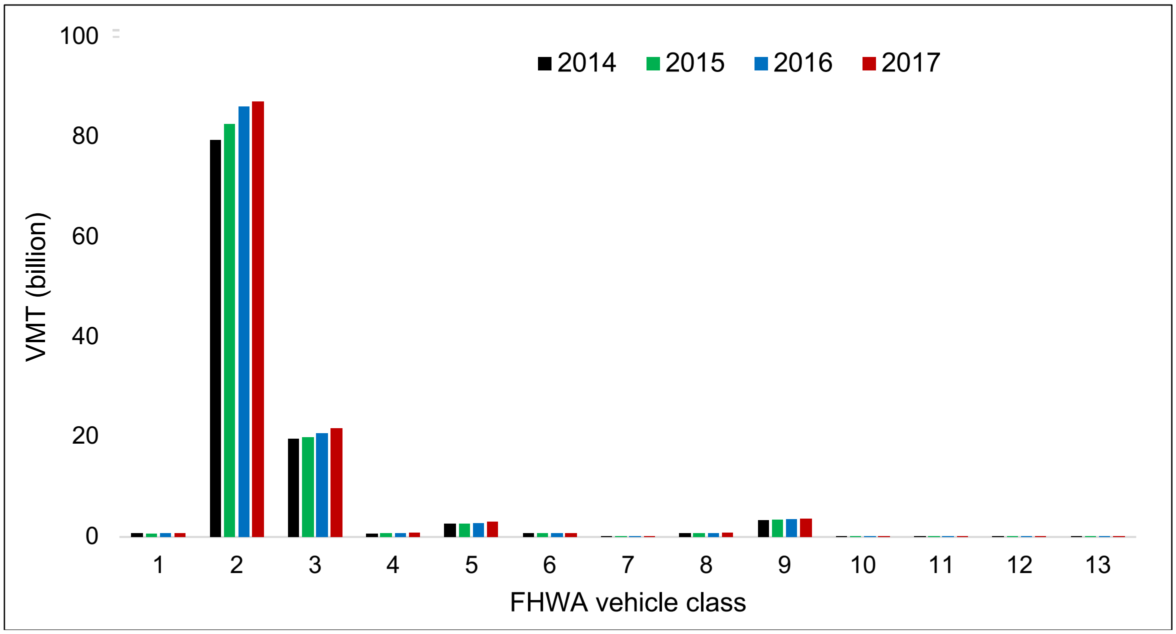


Figure 3.1: Annual NC VMT from 13 vehicle classes, 2014-2017.

Table 3.4: Lane miles under FHWA Functional Roadways and NCDOT Route System.

	NCDOT Route Types						
FHWA Functional Class	**Interstate**	**US**	**NC**	**SR**	**Ramp**	**Others**	**Total**
Interstate	6486.8	5.0	0.0	0.0	898.9	1.7	7392.4
Principal Arterial – Other Freeways and Expressways	207.2	2859.0	345.7	169.6	446.3	124.5	4152.2
Principal Arterial – Other	40.5	8327.0	3085.1	788.0	157.4	198.4	12596.4
Minor Arterial	0.0	4002.6	5091.1	4721.6	20.5	1564.9	15400.7
Major Collector	0.0	1396.7	9427.5	10260.2	4.2	1218.4	22307.0
Minor Collector	0.0	7.9	239.7	12615.7	2.2	153.6	13019.0
Local	0.0	12.6	184.9	103392.3	11.4	76831.6	180432.8
Total	6734.5	16610.7	18373.9	131947.2	1541.0	80093.2	255300.5

Table 3.4 shows the NCDOT maintains 7,392.4 lane miles of interstate (2.9%), 15,748.6 lane miles of principal arterials (6.6%), 15,400.7 lane miles of (6.0%) minor arterials, 15,249 (5.9%) lane miles of collectors, and 180,432.8 (70.7%) lane miles of local roads, according to the FHWA classification. However, the contract information for different projects including design and build, reconstruction, rehabilitation, and maintenance works provided the route information into NCDOT's four route classes, i.e., Interstate, US, State routes or NC routes and secondary routes (SR). Therefore, to allocate these costs we

had to redistribute the reported VMTs from FHWA functional classes to NCDOT's four route system. We used the NCDOT's route characteristics data published by Connect NCDOT (NCDOT, 2021) to find the distribution of lane miles under each of the FHWA functional classes. The ArcGIS shapefile represents the routes and attributes of NCDOT state road system which is comprised of interstate, US, NC, secondary routes, and ramps and all non-state maintained and projected roads that are required for reporting purposes. Each route segment in this file contains a "Route ID", which identifies its classification under NCDOT's route system, and "Functional Class", which identifies the FHWA functional class of the route. Table 3.5 shows the distribution of FHWA roadway lane miles into NCDOT's route system.

Table 3.5: Percentage distribution of FHWA lane miles by NCDOT's highway facility types.

FHWA Functional Class	**NCDOT Routes**			
	Interstate	**US**	**NC**	**SR**
Interstate	99.92%	0.08%	0.00%	0.00%
Principal Arterial – Other Freeways and Expressways	5.78%	79.83%	9.65%	4.73%
Principal Arterial – Other	0.33%	68.03%	25.20%	6.44%
Minor Arterial	0.00%	28.97%	36.85%	34.18%
Major Collector	0.00%	6.62%	44.71%	48.66%
Minor Collector	0.00%	0.06%	1.86%	98.08%
Local	0.00%	0.01%	0.18%	99.81%

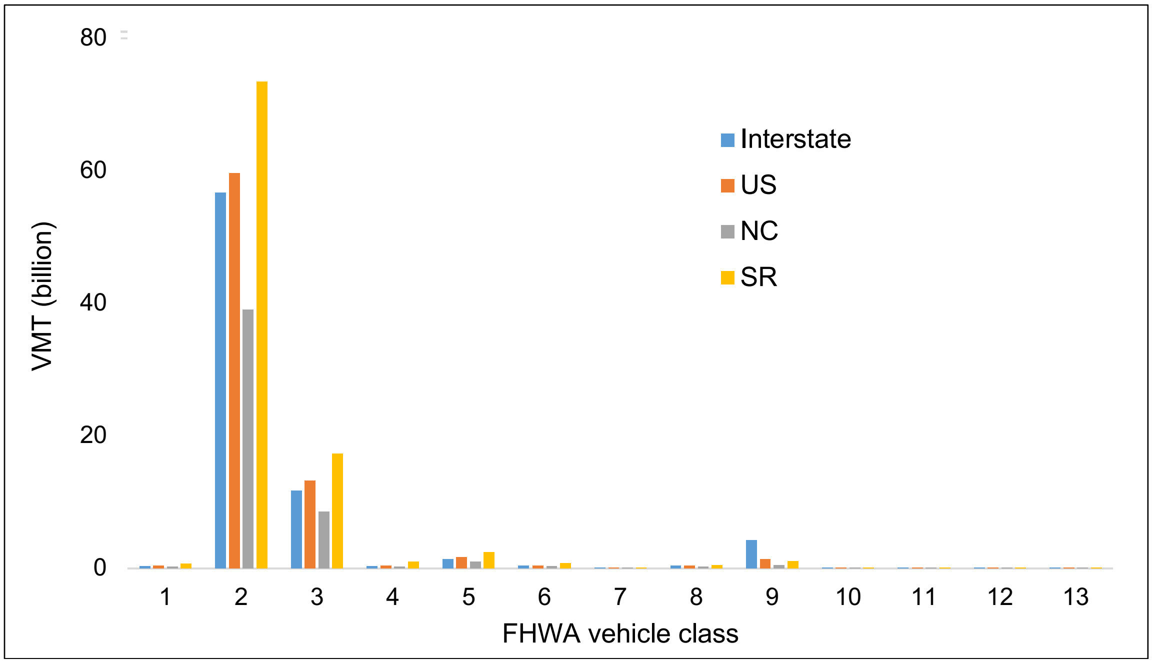
We used the distributions shown in Table 3.5 to allocate the reported VMTs from FHWA functional classes to NCDOT's route system. As per the distribution provided in the Table 3.5, we distributed 99.92% of the FHWA interstate VMT to NCDOT interstate routes and the rest to NCDOT's US routes. Similarly, we distributed 5.78%, 79.83%, 9.65%, and 4.73% of the VMTs on 'PA - Other Freeways and Expressways' to interstate, US, NC, and SR routes, respectively. Table 3.6 shows the distributed VMTs on NCDOT routes. Table 3.7 presents the total VMT for 2014-2017 in urban and rural highway facilities. Figure 3.2 shows the total VMT on urban and rural routes from the 13 vehicle classes during the study period.

Table 3.6: Annual NC VMT (in millions) by vehicle class and by NCDOT route, 2014-2017.

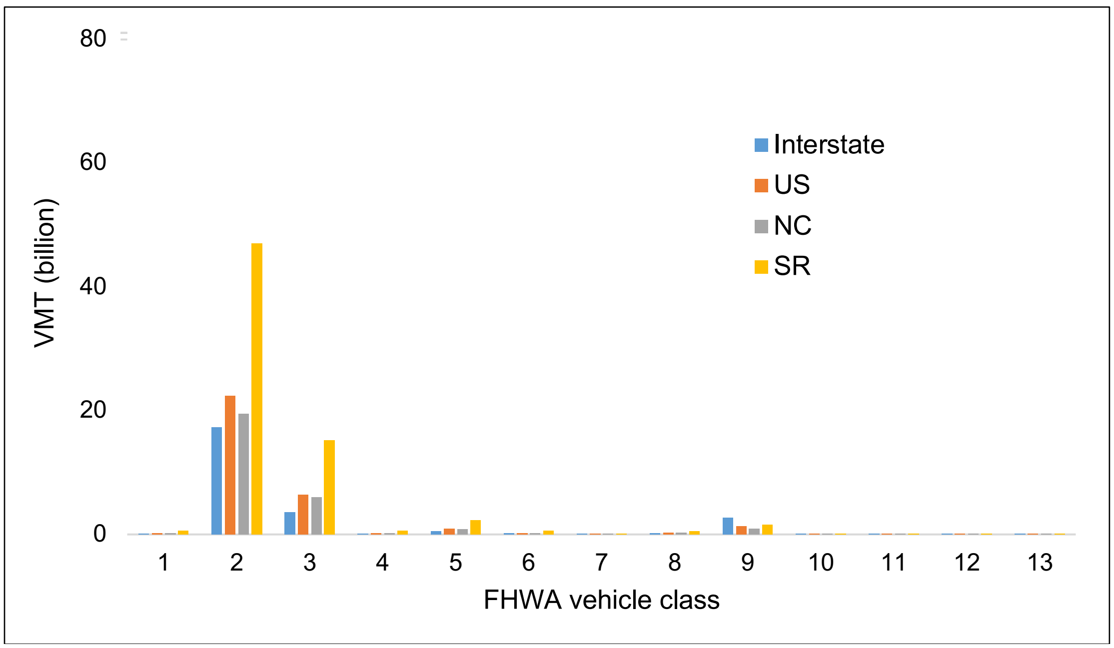
Year	FHWA Vehicle Class	1	2	3	4	5	6	7	8	9	10	11	12	13	
		MC	Cars	2A4T	Bus	2ASU	3ASU	4ASU	4AST	5AST	6AST	5AMT	6AMT	7AMT	Total
2014	Interstate	98.6	17,343.4	3,611.6	121.5	451.9	137.6	7.1	152.6	1,653.8	23.4	32.5	14.7	3.4	23,652.1
	US	151.5	19,501.7	4,630.4	137.9	595.3	148.7	19.0	179.5	643.3	35.9	10.4	4.5	6.7	26,064.9
	NC	117.1	13,939.7	3,505.7	97.9	449.5	106.0	12.3	122.5	371.2	23.9	3.0	1.4	4.6	18,754.7
	SR	328.3	28,570.3	7,930.5	301.2	1,139.5	364.2	21.9	239.4	624.6	38.8	1.7	3.0	4.8	39,568.3
	Total Annual	695.5	79,355.0	19,678.2	658.6	2,636.2	756.5	60.3	694.0	3,293.0	122.0	47.6	23.6	19.6	**108,040.0**
	% VMT	0.64%	73.45%	18.21%	0.61%	2.44%	0.70%	0.06%	0.64%	3.05%	0.11%	0.04%	0.02%	0.02%	1
2015	Interstate	101.7	17,994.9	3,740.7	122.0	454.3	139.5	6.8	151.3	1,682.0	22.5	33.5	15.4	3.6	24,468.1
	US	138.4	20,226.1	4,772.4	148.7	624.3	163.2	20.2	183.5	673.6	40.6	13.9	5.4	8.5	27,018.8
	NC	109.5	14,523.7	3,517.9	104.6	456.8	115.9	12.9	122.1	366.5	25.7	4.0	1.8	5.0	19,366.3
	SR	317.8	29,855.5	7,917.4	400.6	1,159.7	319.3	26.7	262.2	660.8	75.1	3.9	2.0	18.5	41,019.3
	Total Annual	667.5	82,600.2	19,948.4	775.8	2,695.1	737.9	66.5	719.1	3,382.8	164.0	55.3	24.5	35.5	**111,872.5**
	% VMT	0.60%	73.83%	17.83%	0.69%	2.41%	0.66%	0.06%	0.64%	3.02%	0.15%	0.05%	0.02%	0.03%	1
2016	Interstate	106.4	18,837.6	3,916.6	127.4	474.7	145.7	7.1	157.7	1,749.5	23.5	35.0	16.0	3.8	25,600.9
	US	139.6	21,099.5	4,972.1	156.7	653.5	170.8	21.2	193.0	704.7	41.8	15.4	6.0	8.8	28,183.1
	NC	111.6	15,055.5	3,630.5	108.7	472.6	120.8	13.4	126.5	366.9	26.3	4.3	2.0	5.1	20,044.1
	SR	330.8	31,011.2	8,214.6	418.7	1,206.0	333.8	27.7	273.7	689.3	77.8	4.1	2.1	19.2	42,609.1
	Total Annual	688.5	86,003.8	20,733.8	811.6	2,806.9	771.1	69.4	750.8	3,510.4	169.3	58.7	26.2	36.9	**116,437.2**
	% VMT	0.59%	73.86%	17.81%	0.70%	2.41%	0.66%	0.06%	0.64%	3.01%	0.15%	0.05%	0.02%	0.03%	1
2017	Interstate	109.9	19,888.1	4,126.5	135.8	507.8	158.5	7.6	167.8	1,937.5	22.2	38.7	17.8	4.1	27,122.4
	US	136.8	21,229.4	5,282.6	169.9	707.9	177.5	21.9	221.6	702.2	43.8	13.6	4.9	9.9	28,722.0
	NC	100.8	14,980.9	3,814.5	116.1	504.1	116.7	14.1	144.8	365.8	27.0	3.8	1.5	5.7	20,195.8
	SR	338.4	31,026.5	8,513.0	443.4	1,271.4	351.1	29.9	290.1	702.7	70.8	3.9	1.7	20.7	43,063.7
	Total Annual	685.9	87,124.9	21,736.6	865.3	2,991.3	803.9	73.6	824.3	3,708.3	163.8	59.9	25.9	40.4	**119,103.9**
	% VMT	0.58%	73.15%	18.25%	0.73%	2.51%	0.67%	0.06%	0.69%	3.11%	0.14%	0.05%	0.02%	0.03%	

Table 3.7: Total NC VMT (in millions) by facility type, route type, and FHWA vehicle class, 2014-2017.

		Urban Facility				Rural Facility			
Vehicle Class		Interstate	US	NC	SR	Interstate	US	NC	SR
1	MC	320.1	383.9	252.0	727.1	96.6	182.4	186.9	588.3
2	Cars	56692.7	59605.9	39016.9	73406.1	17371.3	22450.8	19482.8	47057.4
3	2A4T	11763.6	13228.1	8522.7	17350.0	3631.8	6429.5	5945.8	15225.5
4	Bus	368.0	400.4	247.3	990.6	138.7	212.8	180.0	573.3
5	2ASU	1379.0	1667.7	1050.8	2474.3	509.7	913.4	832.2	2302.3
6	3ASU	426.6	458.4	288.0	805.0	154.8	201.8	171.3	563.5
7	4ASU	20.9	60.0	35.2	54.0	7.6	22.3	17.5	52.3
8	4AST	391.8	450.5	247.9	510.4	237.5	327.0	268.0	555.0
9	5AST	4331.6	1365.7	520.7	1125.8	2691.1	1358.2	949.6	1551.6
10	6AST	54.5	105.2	61.3	171.0	37.1	56.9	41.6	91.5
11	5AMT	88.0	30.5	7.6	9.9	51.6	22.8	7.5	3.6
12	6AMT	40.0	10.8	3.5	7.5	23.9	10.0	3.3	1.3
13	7AMT	9.5	23.2	13.5	47.9	5.5	10.6	6.8	15.3
Total		75886.4	77790.2	50267.4	97679.6	24957.2	32198.5	28093.5	68580.8



(a) Total NC VMT on urban routes, 2014- 2017.



(b) Total NC VMT on rural routes, 2014-2017.

Figure 3.2: Total NC VMT on (a) urban and (b) rural routes, 2014-2017.

For allocating some of the project costs, this study used FHWA HCAS tool, which requires VMT inputs in 20 vehicle classes. The FHWA tool uses a distribution that combines motorcycle and automobiles in one group and subdivides class 8, 9, 10 and 13 vehicles into three more classes each. That yields a total of 20 vehicle classes, up from

13. This study used those distributions to redistribute the VMT from 13 vehicle classes to 20 vehicle classes; see Table 3.8 for the redistribution.

Table 3.8: Vehicle classification in 1997 Federal HCAS (FHWA, 1997).

20 Vehicle Class Used in FHWA HCAS tool		**FHWA 13 Vehicle Class**
Sl. (Notation)	**Description**	**Sl. (Notation)**
1 (Auto and MC)	Automobiles and motorcycles	Class 1 (MC) and Class 2 (Auto)
2 (LT4s)	Light trucks with 2 axles and 4 tires (pickup trucks, vans, minivans, etc.)	Class 3 (LT4)
3 (SU2)	Single-unit, 2 axle, 6 tire trucks (includes SU2 pulling a utility trailer)	Class 5 (SU2)
4 (SU3)	Single-unit, 3axle trucks (includes SU3 pulling a utility trailer)	Class 6 (SU3)
5 (SU4+)	Single-unit trucks with 4 or more axles (includes SU4+ pulling a utility trailer)	Class 7 (SU4+)
6 (CS3)	Tractor-semitrailer combinations with 3 axles	Class 8 (CB3 and CB4)
7 (CS4)	Tractor-semitrailer combinations with 4 axles	
12 (CT4-)	Truck-trailers combinations with 3 or 4 axles	
8 (3S2)	Tractor-semitrailer combinations with 5 axles, two rear tandem axles	Class 9 (CB5)
9 (CS5)	Tractor-semitrailer combinations with 5 axles, two split (.8) rear axles	
13 (CT5)	Truck-trailers combinations with 5 axles	
10 (CS6)	Tractor-semitrailer combinations with 6 or more axles	Class 10 (CB6+)
11 (CS7+)	Tractor-semitrailer combinations with 7 or more axles	
14 (CT6+)	Truck-trailers combinations with 6 or more axles	
15 (DS5)	Tractor-double semitrailer combinations with 5 axles	Class 11 (DS5)
16 (DS6)	Tractor-double semitrailer combinations with 6 axles	Class 12 (DS6)
17 (DS7)	Tractor-double semitrailer combinations with 7 axles	Class 13 (DS7+)
18 (DS8+)	Tractor-double semitrailer combinations with 8 or more axles	
19 (TS)	Tractor-triple semitrailer or truck-double semitrailer combinations	
20 (Bus)	Buses (all types)	Class 4 (Bus)

Also, FHWA HCAS tool requires the VMT input by highway facilities in both rural and urban areas. Table 3.9 shows the VMT for 20 vehicle classes by facility and route types.

The distribution factors used to split the VMT from 13 FHWA vehicle classes to 20 vehicle classes are included in the appendix (Table 9.1).

Table 3.9: Total VMT (millions) for FHWA 20 vehicle classes by facility type and route type, 2014-2017.

		Urban Facility				Rural Facility			
Vehicle Class		Interstate	US	NC	SR	Interstate	US	NC	SR
1	Auto & MC	57012.8	59989.9	39268.8	74133.2	17467.9	22633.1	19669.8	47645.6
2	LT4	11763.6	13228.1	8522.7	17350.0	3631.8	6429.5	5945.8	15225.5
3	SU2	1379.0	1667.7	1050.8	2474.3	509.7	913.4	832.2	2302.3
4	SU3	426.6	458.4	288.0	805.0	154.8	201.8	171.3	563.5
5	SU4+	20.9	60.0	35.2	54.0	7.6	22.3	17.5	52.3
6	CS3	117.5	135.1	74.4	153.1	71.2	98.1	80.4	166.5
7	CS4	195.9	225.2	124.0	255.2	118.7	163.5	134.0	277.5
8	3S2	3465.3	1092.5	416.6	900.7	2152.9	1086.6	759.7	1241.3
9	CS5	433.2	136.6	52.1	112.6	269.1	135.8	95.0	155.2
10	CS6	40.9	78.9	45.9	128.3	27.8	42.6	31.2	68.6
11	CS7+	2.7	5.3	3.1	8.6	1.9	2.8	2.1	4.6
12	CT4-	78.4	90.1	49.6	102.1	47.5	65.4	53.6	111.0
13	CT5	433.2	136.6	52.1	112.6	269.1	135.8	95.0	155.2
14	CT6+	10.9	21.0	12.3	34.2	7.4	11.4	8.3	18.3
15	DS5	88.0	30.5	7.6	9.9	51.6	22.8	7.5	3.6
16	DS6	40.0	10.8	3.5	7.5	23.9	10.0	3.3	1.3
17	DS7	7.1	17.4	10.1	36.0	4.1	8.0	5.1	11.5
18	DS8+	1.9	4.6	2.7	9.6	1.1	2.1	1.4	3.1
19	TS	0.5	1.2	0.7	2.4	0.3	0.5	0.3	0.8
20	Bus	368.0	400.4	247.3	990.6	138.7	212.8	180.0	573.3
Total		75886.4	77790.2	50267.4	97679.6	24957.2	32198.5	28093.5	68580.8

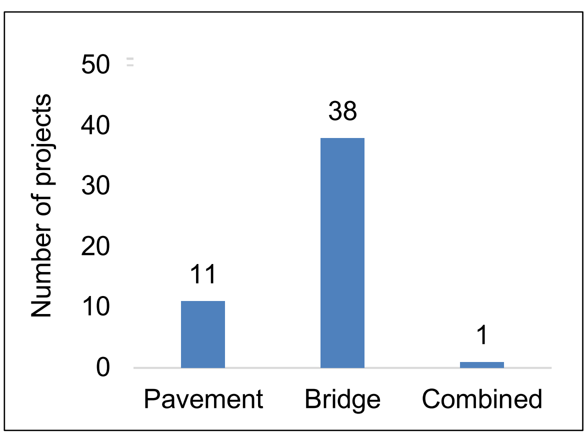
4 Cost Allocation

4.1 Expenditure Data

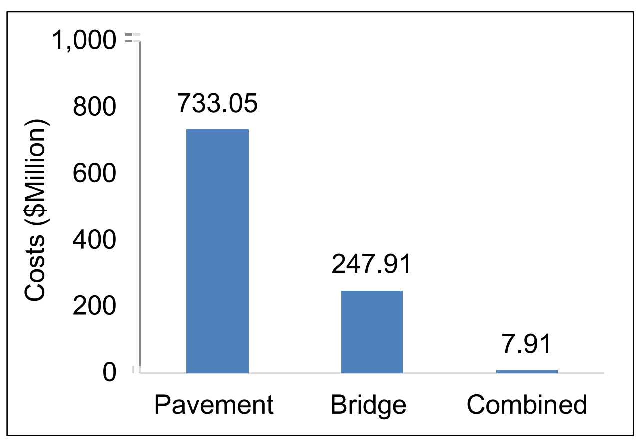
NCDOT provided the list of projects completed within 2014 to 2017 with detailed information including location description, contract type, contract bid amount, and other essential information. Under the "contract type," the projects are divided under three major categories: design and build, resurfacing, and other. There are 50 design and build, 754 resurfacing and 1580 other projects sub-categorized according to the facility type (i.e., pavement, bridge, or both) and type of works (widening, grading, signal and intelligent transportation system, and more). The subcategories by facility types allowed us to allocate the costs for different facility types, and the type of work categories helped us choose the cost allocation method to be used (e.g., for new construction and reconstruction or resurfacing works). The following subsections provide the details of these subcategories.

4.1.1 Design and Build Projects

The design and build projects include constructions of new pavement or replacement of single or multiple bridges. Based on the facility types, we have three sub-categories of design and build projects: 1) Pavement-related; 2) Bridge-related; 3) Combined pavement and bridge. Figure 4.1 demonstrates the number of each subcategory of design and build projects (a) and total expenditures (b). Total expenditures in pavement and bridge related projects are \$733.05 million and \$247.91 million, respectively. Only one project has been categorized as combined design and build, with a cost of \$7.91 million.



(a) Types of Design and Build projects

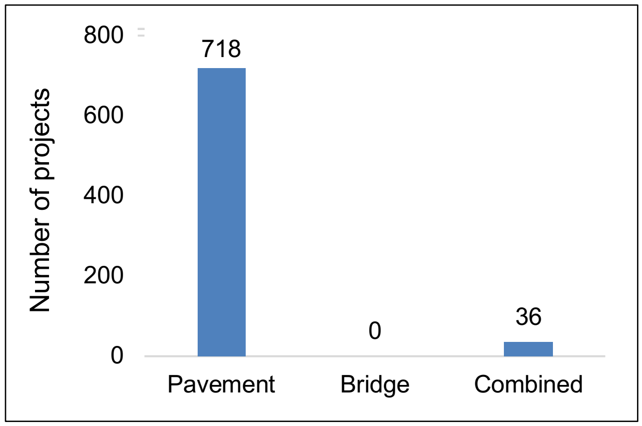


(b) Cost Distribution in Design and Build Category

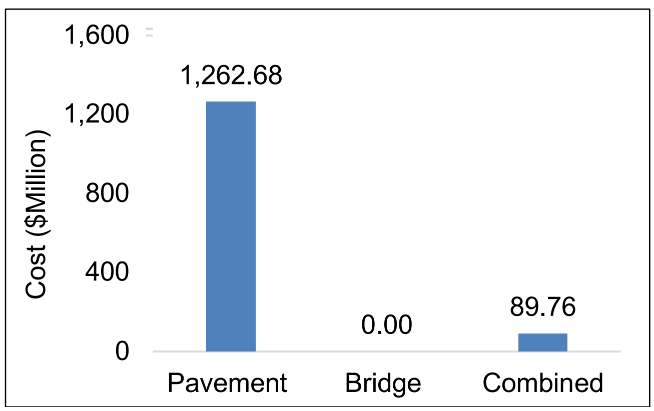
Figure 4.1: Sub-categories of Design Build projects.

4.1.2 Resurfacing

Resurfacing projects are also divided into three subcategories: 1) Pavement-related resurfacing; 2) Bridge-related resurfacing; and 3) Combined pavement and bridge related resurfacing projects. Figure 4.2 shows the number of projects in each category (a) and the cost of each category (b).



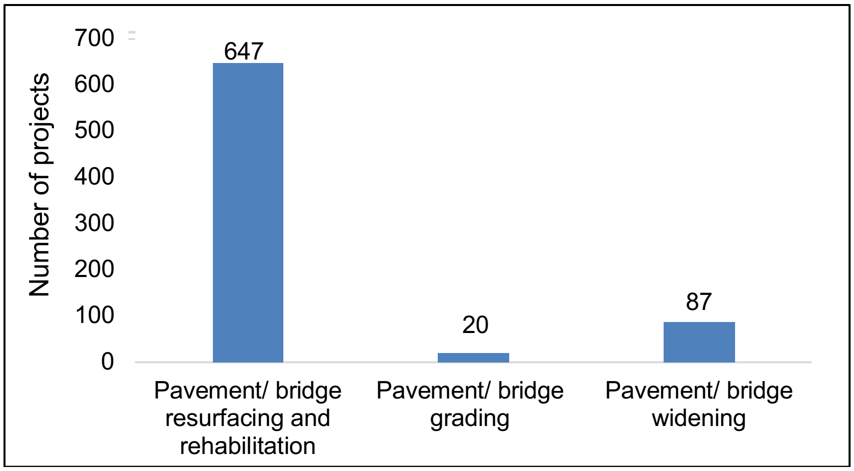
(a) Types of Resurfacing projects



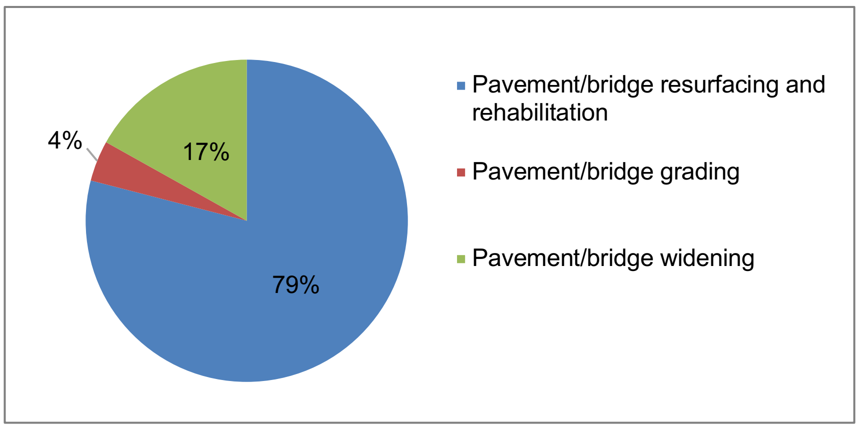
(b) Cost of Resurfacing projects on different facilities

Figure 4.2: Sub-categories of resurfacing projects by facility type.

Most resurfacing projects are pavement-related, and the total expenditure from those projects totaled $1.26 billion. Resurfacing projects are further classified into three categories based on to the contract description: 1) Type 1: Pavement/bridge resurfacing and rehabilitation; 2) Type 2: Pavement/bridge grading; and 3) Type 3: Pavement/bridge widening. Figure 4.3 shows the number of each subcategory of resurfacing project (a) and the cost shares of each (b). Table 4.1 provides a breakdown of resurfacing project costs by subcategory. These projects mainly include rehabilitation works such as milling, patching, and resurfacing.



(a) Types of resurfacing projects



(b) Costs shares among different types of resurfacing projects.

Figure 4.3: Subcategories of resurfacing projects.

Table 4.1: Resurfacing project costs ($Millions) by project subcategories, 2014-2017.

Facility	Pavement		Combined		Total
Type	**#**	**Expenditure**	**#**	**Expenditure**	**Expenditures**
Pavement/bridge resurfacing and rehabilitation	617	992.70	30	76.02	1,068.71
Pavement/bridge grading	20	55.26	0	0.00	55.26
Pavement/bridge widening	81	214.72	6	13.74	228.46
Total	718	1,262.68	36	89.76	1,352.43

4.1.3 Other Projects

The projects under the "Other" category are divided into four categories based on the facility types: 1) pavement, 2) bridge, 3) combined, and 4) miscellaneous. Some of the projects under "Other" do not specify facilities and instead name weight station, rest areas, signals and signage, safety improvements, ornamental plantings, and so on under the description tab. These items were subcategorized as the miscellaneous projects. Projects under each of the four sub-categories (pavement, bridge, combined pavement and bridge and miscellaneous) are further divided into six different types based on contract descriptions:

Type 1: Surface treatment/rehabilitation/preservation/drainage works

Type 2: Pavement/bridge widening

Type 3: Replacement of bridge or pavement structures

Type 4: Installing traffic operation and monitoring devices.

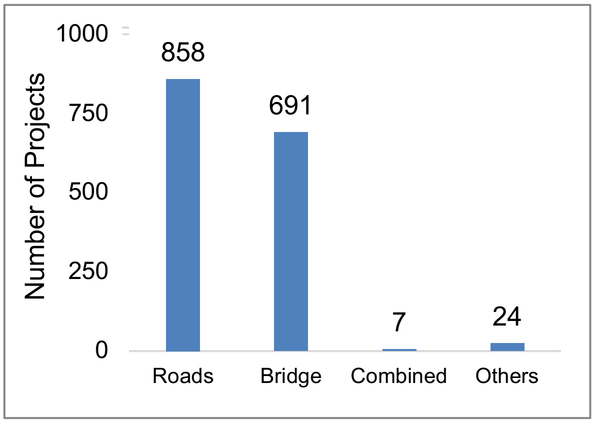
Type 5: Safety, sidewalks, rest area, access ramp, access road, curb ramp, median, landscape, and other works

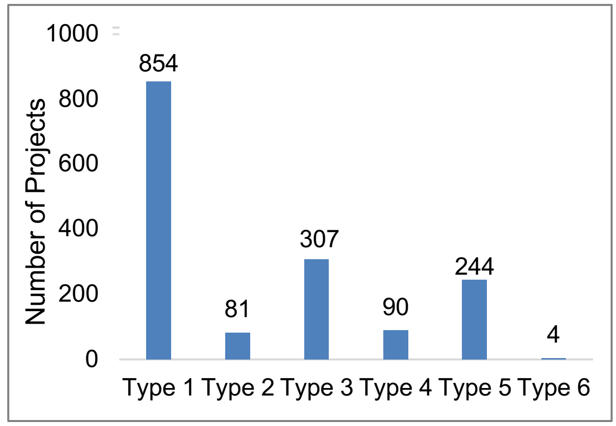
Type 6: Weigh stations

Table 4.2 summarizes the expenditures of these "Other" subcategories, and Figure 4.4 provides a breakdown of the subcategories by facility and type of work.

Table 4.2: Subcategories of Other project expenditures ($Millions), 2014-2017.

Facility	Pavement		Bridge		Mixed		Miscellaneous		Total Cost
Type of Projects	**#**	**Cost**	**#**	**Cost**	**#**	**Cost**	**#**	**Cost**	
Type 1: Surface treatment/ rehabilitation/ preservation/ drainage works	457	1,364.67	379	592.85	6	16.63	12	87.11	2,061.25
Type 2: Pavement/bridge widening	73	281.60	7	9.08	0	0.00	1	13.65	304.34
Type 3 Replacement of bridge or pavement structures	26	13.58	281	180.86	0	0.00	0	0.00	194.44
Type 4: Installing traffic operation and monitoring devices	85	120.20	2	0.51	1	0.13	2	0.22	121.06
Type 5: Safety, sidewalks, rest area, access ramp, access road, curb ramp, median, landscape, and other works	213	49.26	22	11.35	0	0.00	9	12.39	73.00
Type 6: Weigh stations	4	1.80	0	0.00	0	0.00	0	0.00	1.80
Total	**858**	**1,831.11**	**691**	**794.65**	**7**	**16.76**	**24**	**113.36**	**2,755.89**





(a) Other projects by facility type. (b) Other projects by type of work.

Figure 4.4: Subcategories of Other projects by (a) facility type and (b) type of work.

The total expenditures from all "Other" projects for the four analysis years is $2.76 billion. The cost share of each of the six types of Other projects is shown in Figure 4.5.

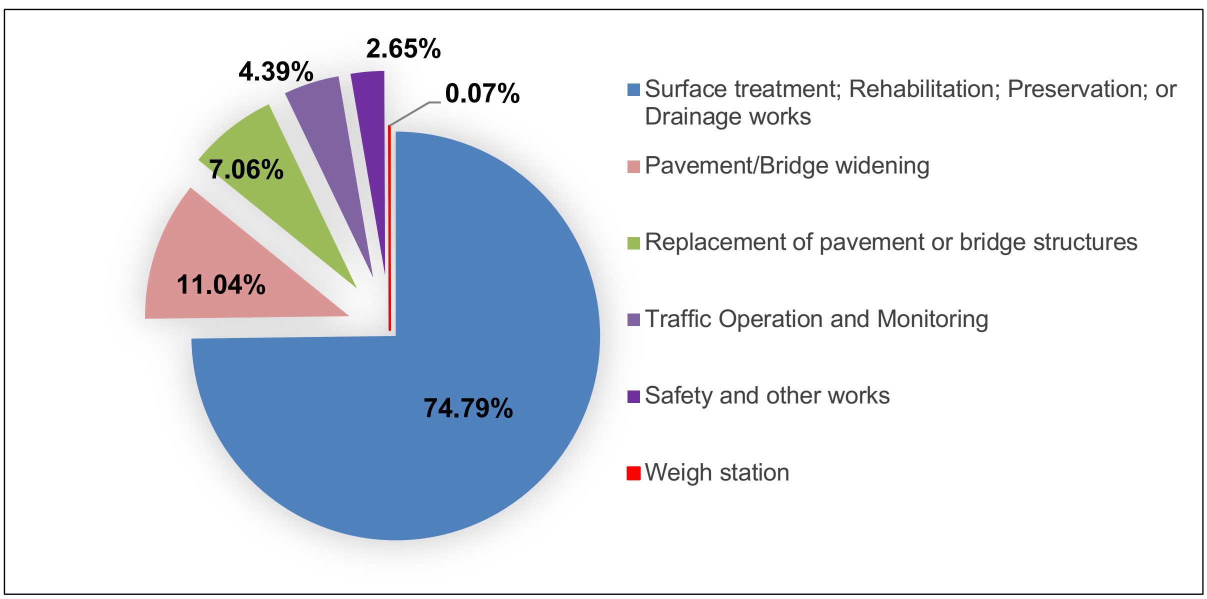


Figure 4.5: Percentage cost share by type of work for Other projects, 2014-2017.

From Figure 4.5, we see that major portion of the expenditures is from the surface treatment, rehabilitation, preservation, and drainage works. Some major construction/reconstruction works are included in the pavement and bridge widening works and the bridge replacement projects. Therefore, the detail lists of expenditure items are requested from NCDOT for these two types of Other projects with contract bid amount more than $1 million.

Table 4.3 shows the number of projects by types of works on different facilities during each year from 2014 to 2017.

Table 4.3: Subcategories of Other project expenditures.

Year	**2014**			**2015**			**2016**			**2017**		
Categories	**Design Build**	**Resur- -facing**	**Other**	**Design Build**	**Resur- -facing**	**Other**	**Design Build**	**Resur- -facing**	**Other**	**Design Build**	**Resur- -facing**	**Other**
Pavement	2	196	162	5	207	165	1	183	253	3	132	278
Bridge	2	1	225	8	0	191	13	0	129	15	0	146
Both	0	10	2	0	12	0	1	7	4	0	7	1
Miscellaneous	0	0	2	0	0	6	0	0	4	0	0	12
Total	4	207	391	13	219	362	15	190	390	18	139	437
Total (annual)	602			594			595			594		

Approximately 600 projects are completed on an annual basis, with most projects being pavement related. From the total expenditure perspective, 2015 had the highest amount of expenditure, $1.48 billion in 594 projects. Figure 4.6 and Figure 4.7present the number and expenditures, respectively, from all of the projects on different facilities from 2014 to 2017.

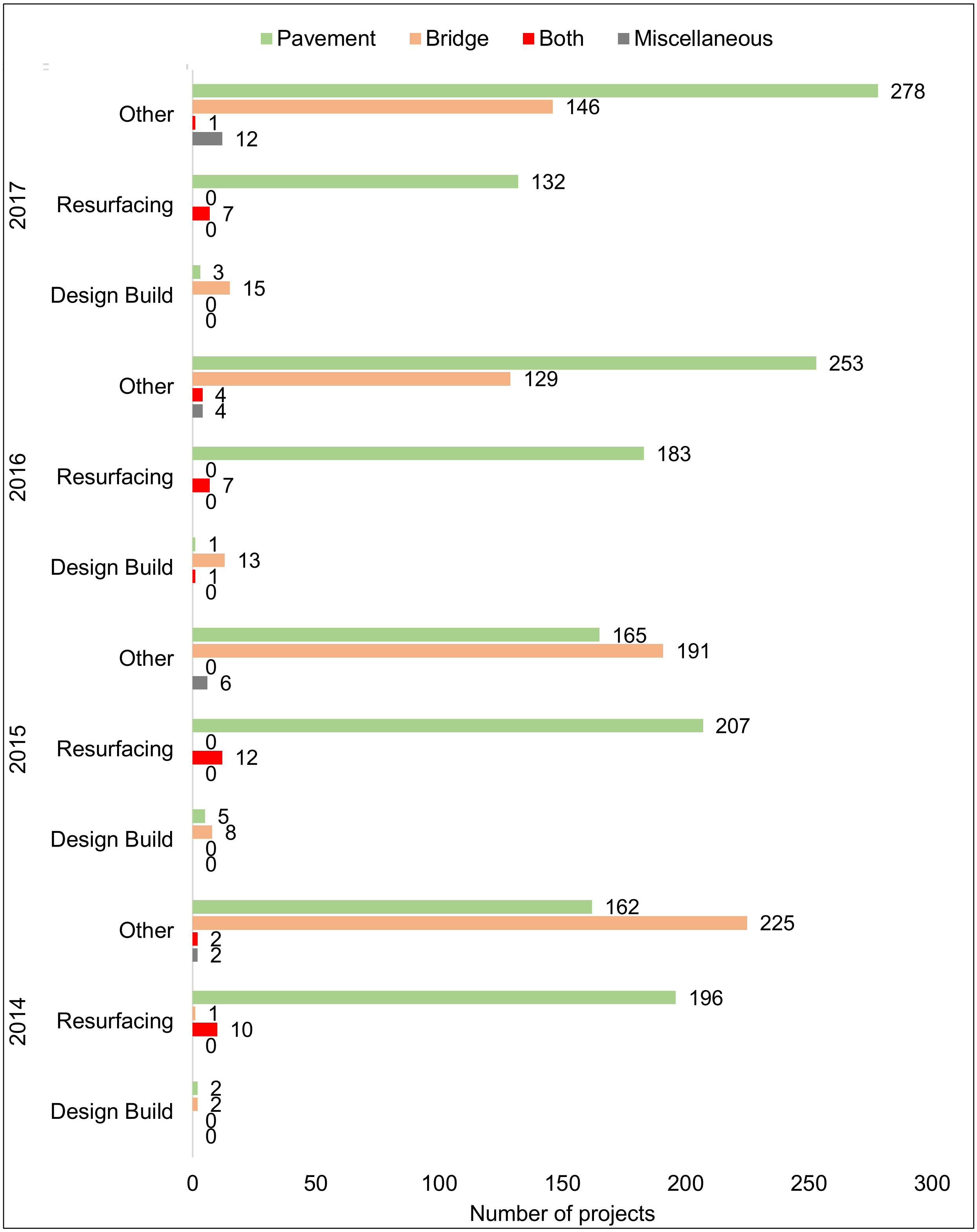


Figure 4.6: Number of projects by year, project type, and facility type.

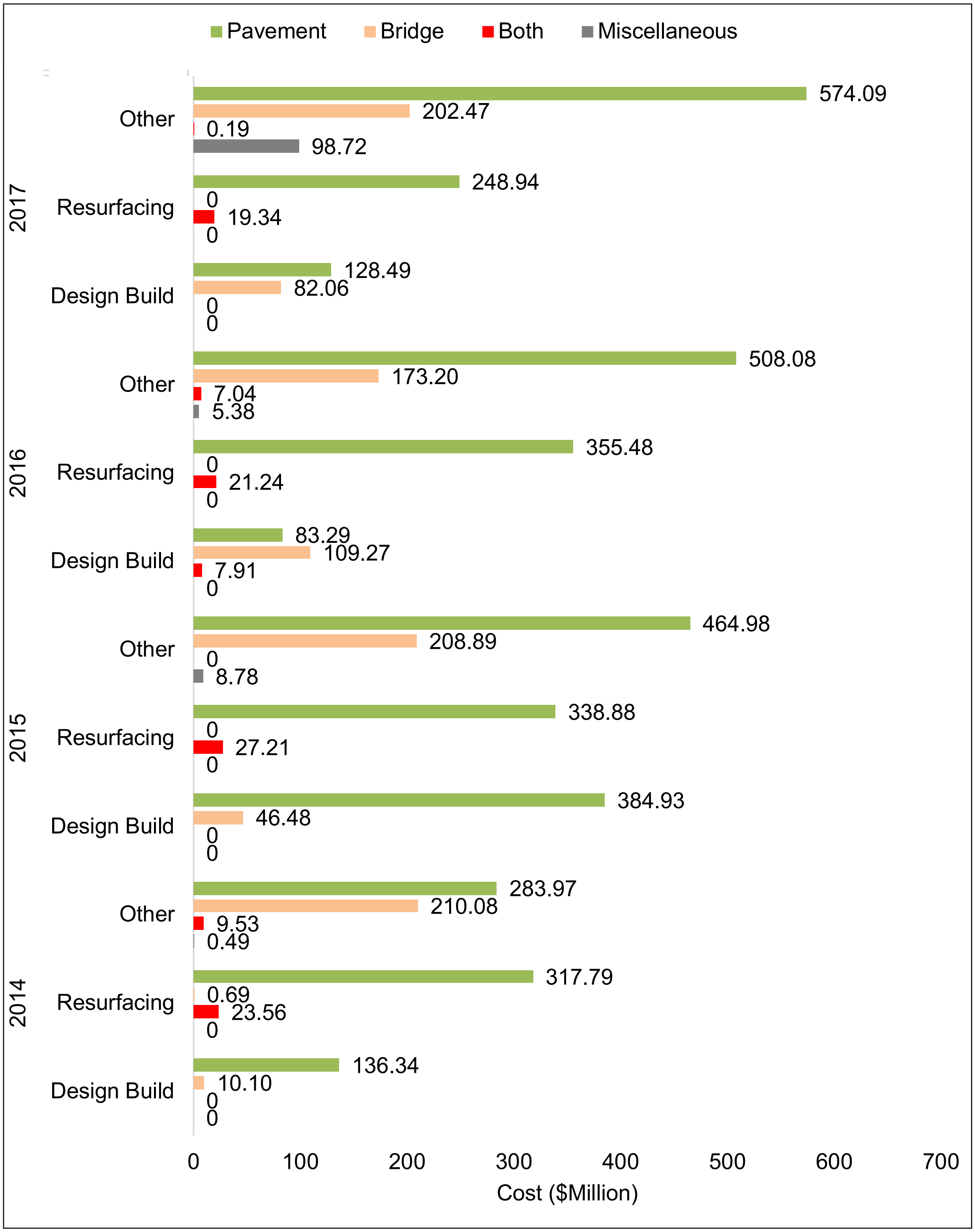


Figure 4.7: Project costs by year, project type, and facility type.

4.2 Cost Allocation of Pavement-related Project Expenditures

4.2.1 New Pavement

4.2.1.1 Methodology

The FHWA model for state HCAS allows analysts to use either of the two cost allocation approaches for new construction projects, i.e., the deterioration approach (used for rehabilitation projects) or the thickness-based approach. We use the thickness-based option (also known as the incremental approach) as it has been used more frequently by other states. As described in the FHWA HCAS tool (FHWA, 2000, FHWA, 1997), new pavement construction costs are separated into two components: cost of the base facility and cost of the remaining facility. The base facility is the structural component that serves as the platform for the remaining facility. In this method, we had to choose a minimum pavement thickness, which is represented by the structural number (SN) for flexible pavement and slab thickness in inches for rigid pavement. We used the following definitions as the base facility for flexible and rigid pavements (Volovski et al., 2015):

- Flexible pavements: 1 inch of surface course, 2 inches of intermediate course and 3 inches of base course.
- Rigid pavements: 5 inches of Portland cement concrete (PCC) slab

For flexible pavement, the SN is calculated to be 2.22, using the building materials and layer coefficients suggested by NCDOT (NCDOT, 2019). The base facility design is considered adequate for light vehicles and is viewed as a common cost for all vehicle classes. Therefore, the base facility cost is allocated using non-load related allocator, such as VMT and PCE-adjusted VMT. PCE factors represent the capacity and congestion impact of different truck traffic on the roadways relative to the passenger car. Heavier vehicles such as trucks, buses, and recreational vehicles typically deteriorate the highway operating conditions more quickly as they have lower speed and larger headways compared to passenger vehicles. PCE factors are introduced to capture the impacts of trucks, buses, and recreational vehicles on highway operation (TRB, 2000, 1994). This study allocated the base facility cost based on PCE-adjusted VMT using the average PCE factors suggested by the Highway Capacity Manual 2000 (TRB, 2000).

Table 4.4: Average PCE factor on different highway facilities.

Vehicle Class	Interstate Routes	Non-Interstate Routes
Single-unit Trucks: Class 4-7	1.35	2.2
Multi-unit Trucks: Class 8-13	1.6	2.2

Additional pavement thickness is required to accommodate the VMT from different vehicles (ECONorthwest, 2021; Volovski et al., 2015). Therefore, the cost of the remaining facility is allocated based on the operating weights and size of the different vehicle classes. Usually, a higher portion of the cost is allocated to the successively larger and heavier vehicles (ECONorthwest, 2019). The number and configuration of axles also plays a significant role on the amount of damage to the pavement. A small number of axles carrying higher loads will impart more damage to the pavement, while increasing the number of axles for the same total load will reduce the amount of damage to the pavement (Salama et al., 2006). Truck damage factors for 2-axle vehicles have been found to be 3.33 times and 5.45 times the 3-axle vehicles and 6-axle semi-trailers, respectively (Raheel et al., 2018). FHWA HCAS tool allocates the remaining facility costs based on the AASHTO pavement design procedures (AASHTO, 1993a). This method uses relative ESALs from each vehicle class to allocate the remaining facility cost. At first, the design ESAL for the pavement structure is determined using 1993 AASHTO guideline. Then the ESAL's contribution from each vehicle class is estimated using the load equivalence factor (LEF). LEF represents the impacts from different types of axle load (i.e., single, tandem, tridem, or quad axle) relative to the standard 18-kip single axle load. Finally, the number of ESALs covered by the base facility is subtracted from the total ESALs, and the remaining ESAL is held responsible for the remaining cost of the pavement structure.

For operating weight, we used weigh-in-motion (WIM) data provided by NCDOT. This data set included operating gross vehicle weight (GVW) of truck traffic, i.e., FHWA class 4 to class 13 vehicles on 11 interstates, 22 US routes, one NC route, and one secondary route. In this study, we followed the NCDOT's WIM data for interstate and US routes and FHWA's default distribution for the other highway routes. The NCDOT data, however, did not include operating weights by axle type and vehicle class. Therefore, we used the default axle weight distribution provided in the FHWA HCAS tool instead. The results presented in the following sections are calculated using NCDOT's operating GVW data for interstates and US routes, FHWA's operating weight distributions for the other route types, and FHWA's axle weight distributions.

4.2.1.2 New Pavement Projects

Only two of the 40 new pavement projects are rigid pavement, and the remaining 38 are flexible pavement projects. Among these 38, two are on interstate routes, seven on US routes, ten on NC routes, and 19 on secondary routes. The new rigid pavement projects are on one interstate and one NC route. Among these, some new construction projects include both pavement and bridge-related expenditures. The pavement-related expenditures of those projects are added with the new pavement construction expenses and allocated as per the new pavement construction or reconstruction allocation procedure. Table 4.5 gives the breakdown of new pavement project costs by year and facility type.

Table 4.5: Total costs ($Millions) of new flexible and rigid pavement projects by year and facility type.

Year	Flexible				Rigid			
	Interstate	US	NC	SR	Interstate	US	NC	SR
2014	0.00	0.00	0.00	1.56	0.00	0.00	0.00	0.00
2015	97.39	55.69	16.90	52.30	139.70	0.00	0.00	0.00
2016	84.15	0.00	1.81	18.86	0.00	0.00	0.00	0.00
2017	0.00	133.41	15.20	29.08	0.00	0.00	18.47	0.00
Total	181.53	189.10	33.91	101.80	139.70	0.00	18.47	0.00
Average annual	45.38	47.27	8.48	25.45	34.93	0.00	4.62	0.00

From 2014 to 2017, the total expenditure on new pavement projects was $664.5 million ($506.3 million in flexible and $158.2 million in rigid pavement projects). For flexible and rigid pavements, the highest expenditures are for US and interstate routes, respectively. The research team used the county information under the project description to decide whether the projects were carried out on urban or rural areas. The counties were designated as urban or rural using based on the percentage of population living in urban and rural areas (NC.gov, 2015).

Major work categories in the new construction and/or major reconstruction works on pavement and bridges include grading, traffic control, signal, signs, pavement marking, utility, wall, right of way, paving (structural works), bridge, culvert, fence, guardrail, landscape, lighting, and miscellaneous. The cost under these categories was categorized in five groups: group 1 include grading, traffic control, pavement marking costs; group 2 include paving (structural work) costs; group 3 include bridge and/or culvert related costs; group 4 and 5 include right or way acquisition cost and miscellaneous costs, respectively. Groups 2 and 3 include load-related costs, and groups 1, 4, and 5 include non-load related or common costs. The common costs are allocated based on PCE-miles and the load-related costs are allocated using the FHWA HCAS tool.

Several pavement projects provide a full itemization of cost details, such as project numbers C202067 and C202622, with the "Miscellaneous" category comprising less than 10% of the total cost. The "Miscellaneous" categories of these projects did not need additional sub-categorization. List items under "Miscellaneous" mostly include mobilization, site office, and other lump sum values. On the other hand, other pavement projects list most of the costs under "Miscellaneous.". For example, bridge projects C20283 and C20284 and pavement projects C202523 and C202615 state that the "Miscellaneous" share is almost 100% of the total project cost. Moreover, the list items under the category only include design and construction and mobilization work.

Therefore, the research team investigated the details of similar projects that included detailed cost items. Seven out of the 40 new pavement projects assign more than 95% of the total cost to “Miscellaneous,” but unfortunately, none of them include a detailed list of cost items within that category. The distribution shown in Figure 4.8, which is based on new pavement projects with detailed cost items, was applied to the pavement projects which do not have detailed cost items. The total costs for those projects were therefore redistributed as 51.45% (47.66% + 3.79%) to paving or structural costs and the rest 48.55% to common cost.

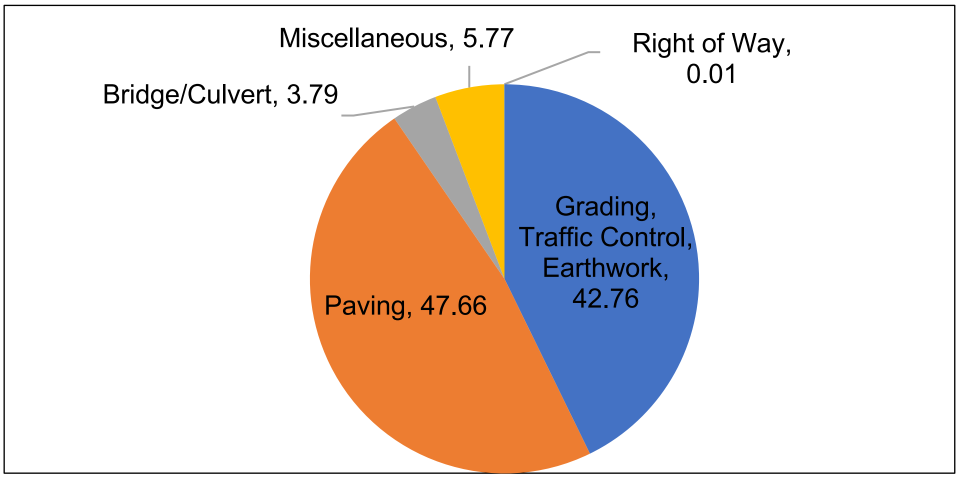


Figure 4.8: Cost distribution in new pavement projects.

4.2.1.3 New Pavement Cost Allocation Results

Table 4.6 presents the allocated costs from new pavement projects to 13 FHWA vehicle classes on four highway facilities. Costs for the entire analysis period (2014-2017) are allocated to the 13 FHWA vehicle classes using the combined VMT from 2014 to 2017. Costs are allocated for each of the four highway facilities and then added to find the combined costs on all highway facilities. Figure 4.9 shows the total costs from the new pavement projects allocated to 13 vehicle classes.

Table 4.6 Cost responsibility ($Millions) by facility type and vehicle class for new pavement projects, 2014-2017.

Vehicle Class		Interstate	US	NC	SR	All Facilities	All Facilities (%)
MC	1	0.80	0.64	0.21	0.56	2.20	0.33%
Cars	2	141.49	92.85	27.91	51.00	313.25	47.14%
2A4T	3	45.56	36.47	11.60	25.10	118.72	17.87%
Bus	4	3.55	2.75	0.80	2.74	9.84	1.48%
2ASU	5	9.88	10.53	3.69	8.63	32.73	4.93%
3ASU	6	4.29	4.22	1.04	2.82	12.38	1.86%
4ASU	7	0.44	1.21	0.14	0.25	2.05	0.31%
4AST	8	5.23	5.18	1.24	2.33	13.98	2.10%
5AST	9	105.18	31.68	5.22	7.40	149.49	22.50%
6AST	10	1.34	2.06	0.35	0.70	4.45	0.67%
5AMT	11	2.22	0.67	0.06	0.04	2.99	0.45%
6AMT	12	0.79	0.20	0.03	0.03	1.05	0.16%
7AMT	13	0.45	0.63	0.09	0.20	1.38	0.21%
Total Cost		321.22	189.10	52.39	101.80	664.51	100%

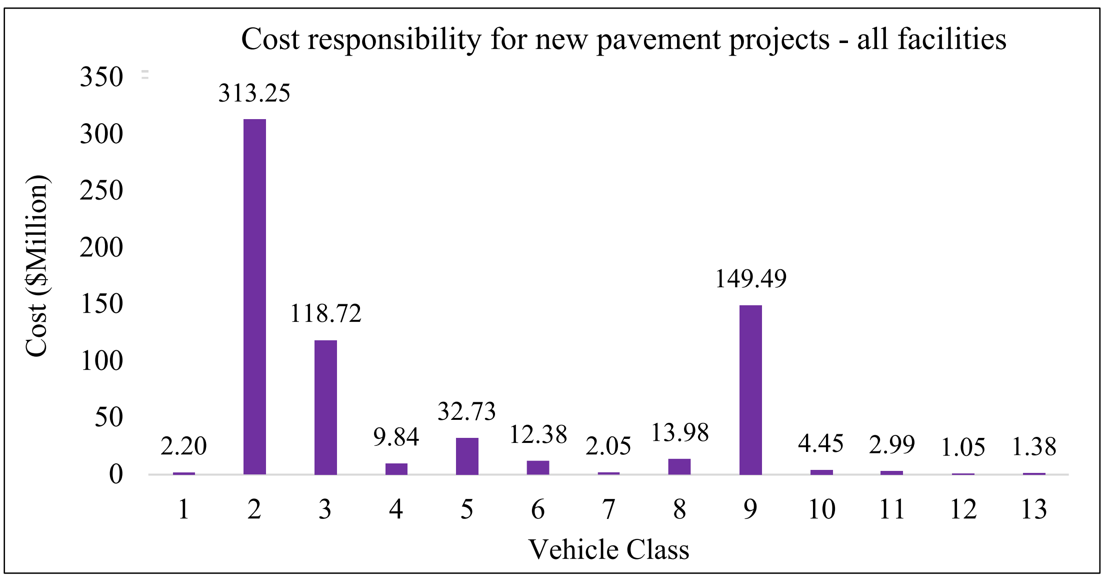


Figure 4.9: Cost responsibility ($Million) for new pavement projects by vehicle class on all facilities, 2014-2017.

Table 4.7 Table 4.7: Unit cost ($/VMT) by facility type and vehicle class for new pavement projects, 2014-2017.presents the cost responsibilities in $/VMT unit from all load and non-load related costs from new pavement projects. Figure 4.10 through Figure 4.13 show the unit cost in $/VMT for interstate, US, NC, secondary and mixed routes, respectively.

Figure 4.14 shows the unit cost for all the facility types. Figure 4.15 compares the unit costs of the 13 vehicle classes on four highway facilities.

Table 4.7: Unit cost ($/VMT) by facility type and vehicle class for new pavement projects, 2014-2017.

Vehicle Class		Interstate	US	NC	SR	All Facility
MC	1	0.0019	0.0011	0.0005	0.0004	0.0008
Cars	2	0.0019	0.0011	0.0005	0.0004	0.0009
2A4T	3	0.0030	0.0019	0.0008	0.0008	0.0014
Bus	4	0.0070	0.0045	0.0019	0.0018	0.0032
2ASU	5	0.0052	0.0041	0.0020	0.0018	0.0029
3ASU	6	0.0074	0.0064	0.0023	0.0021	0.0040
4ASU	7	0.0155	0.0147	0.0027	0.0024	0.0076
4AST	8	0.0083	0.0067	0.0024	0.0022	0.0047
5AST	9	0.0150	0.0116	0.0036	0.0028	0.0108
6AST	10	0.0146	0.0127	0.0034	0.0027	0.0072
5AMT	11	0.0159	0.0125	0.0037	0.0030	0.0135
6AMT	12	0.0124	0.0097	0.0038	0.0031	0.0104
7AMT	13	0.0301	0.0187	0.0044	0.0032	0.0104

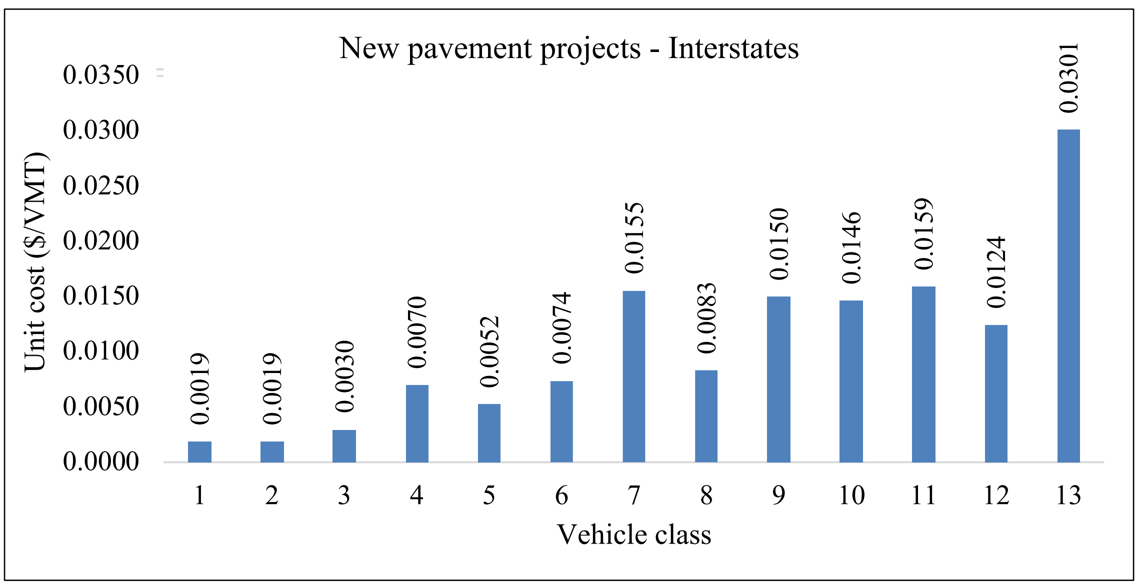


Figure 4.10: Unit Cost ($/VMT) for new pavement projects on interstates, 2014-2017.

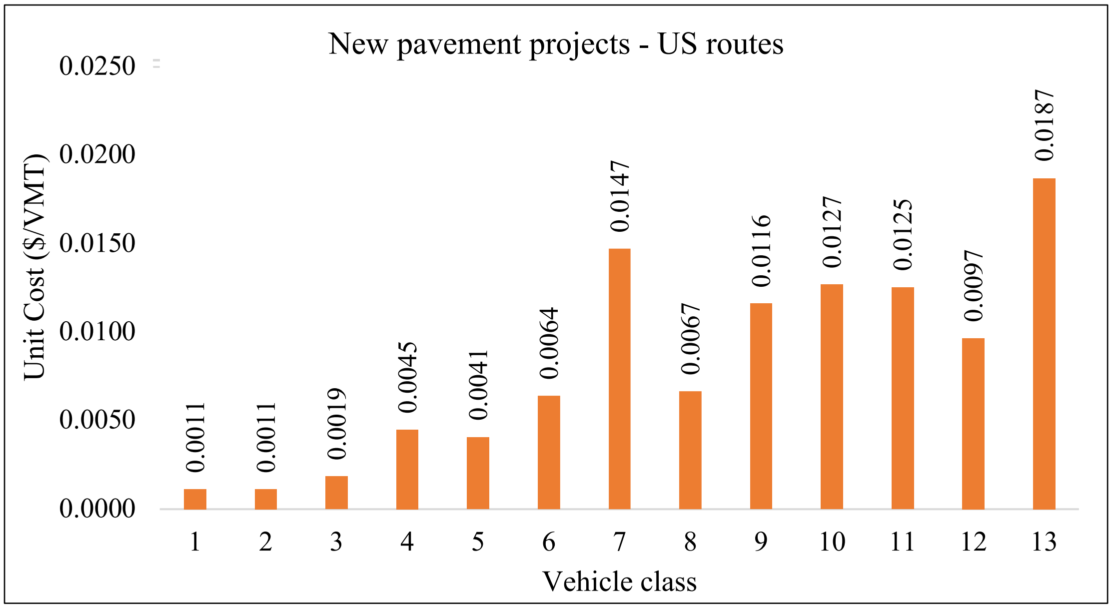


Figure 4.11: Unit cost ($/VMT) for new pavement projects on US routes, 2014-2017.

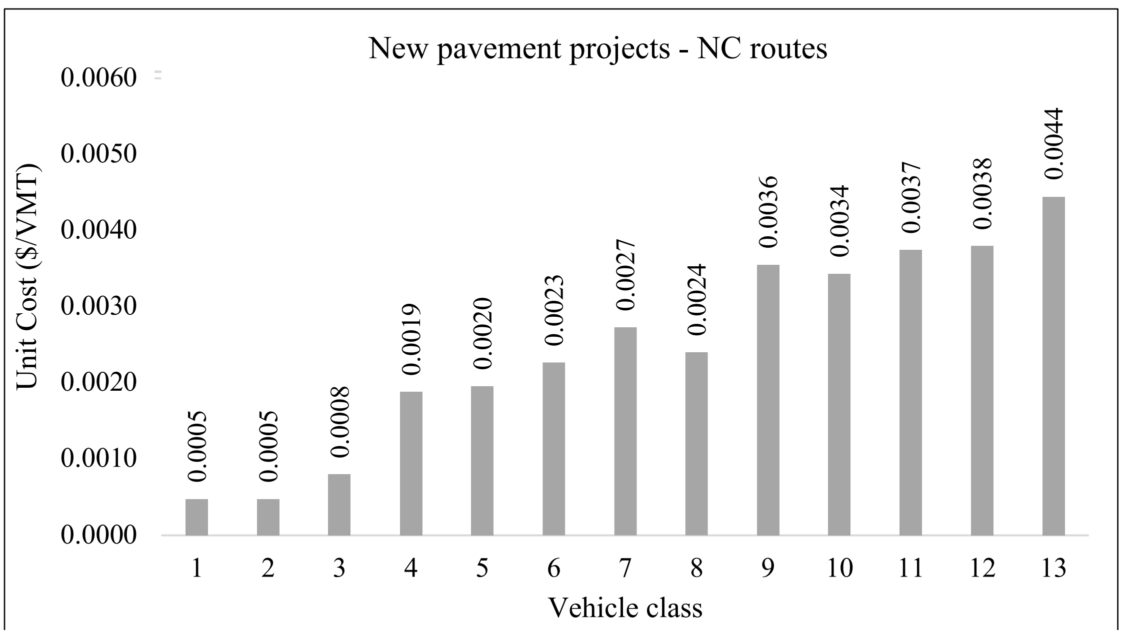


Figure 4.12: Unit cost ($/VMT) for new pavement projects on NC routes, 2014-2017.

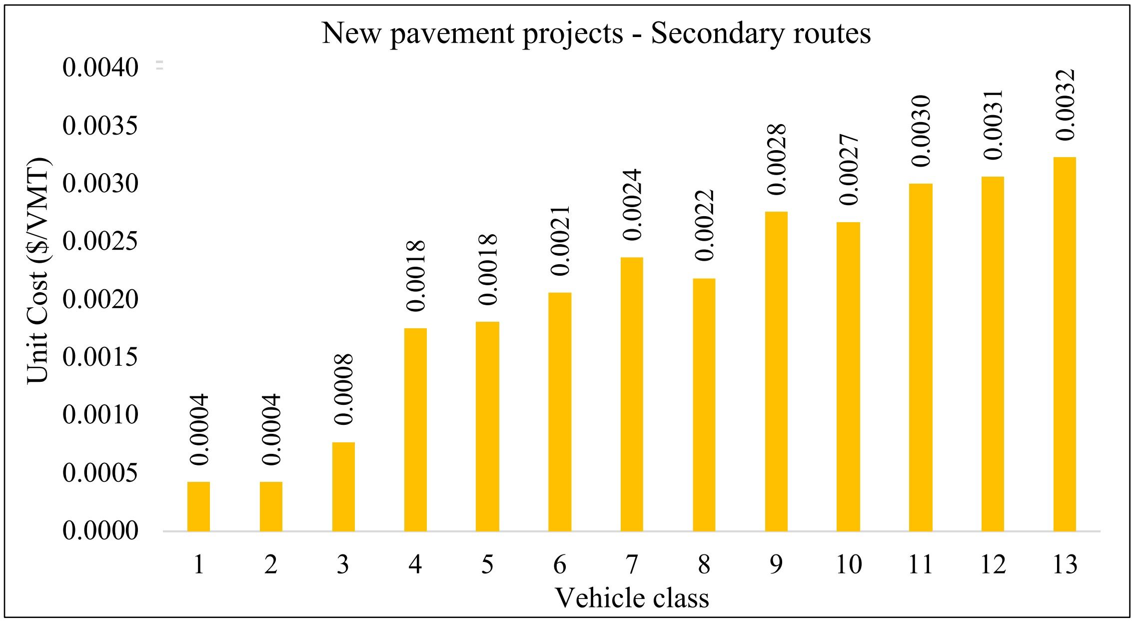


Figure 4.13: Unit Cost ($/VMT) for new pavement projects on secondary routes, 2014-2017.

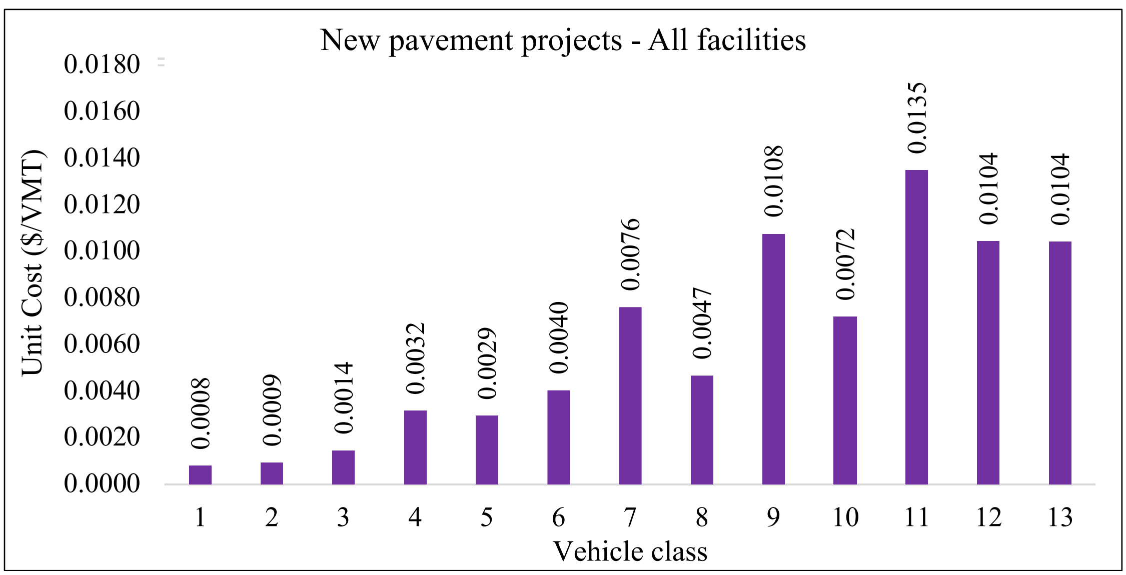


Figure 4.14: Unit Cost ($/VMT) for new pavement projects on all highway facilities, 2014-2017.

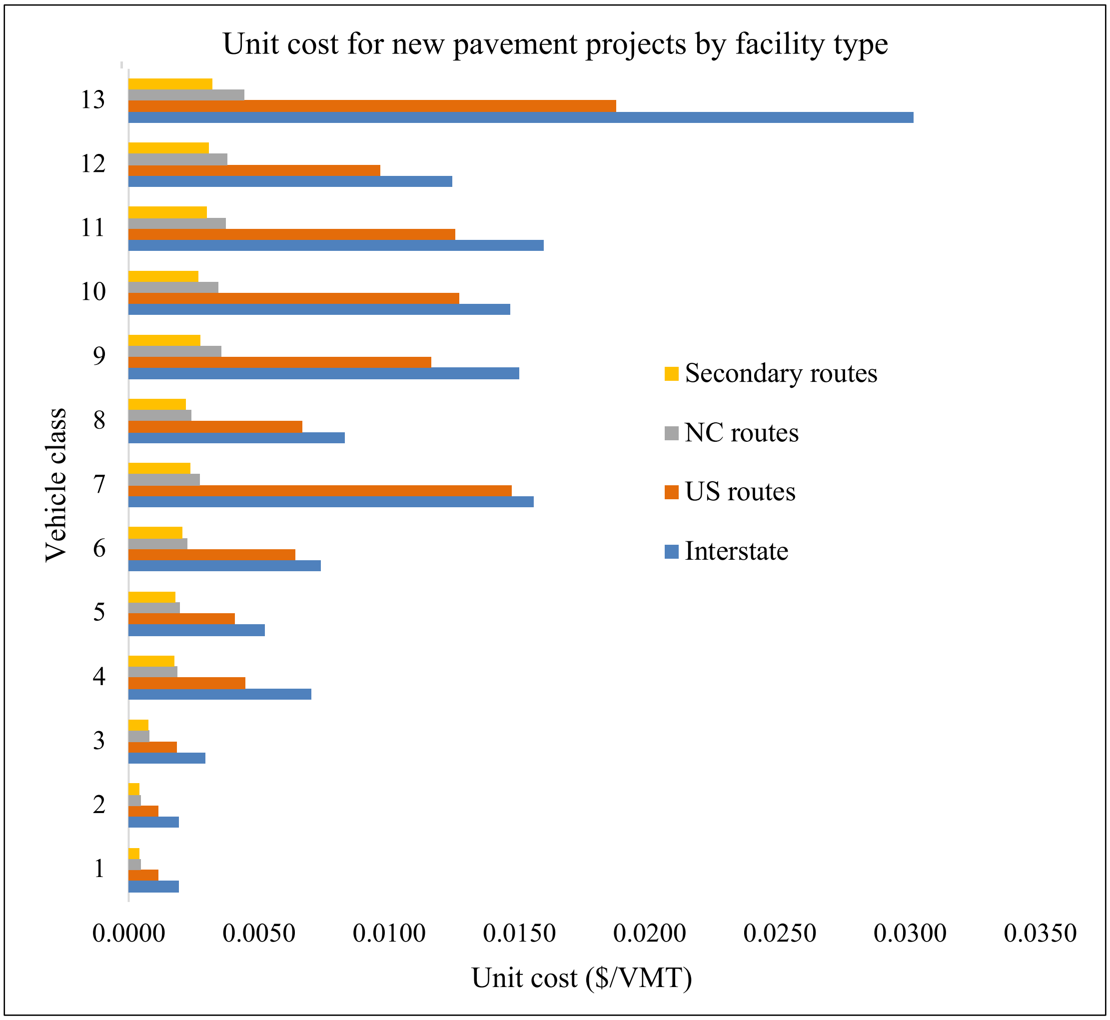


Figure 4.15: Unit cost ($/VMT) for new pavement projects by facility type, 2014-2017.

From Table 4.7 and Figure 4.15, we see that the highest unit cost is associated to vehicle class 13 for all types of highway facilities. The costs are allocated by highway facility type using the expenditures data of the new pavement projects on each highway facility. Unit costs on each highway facility are calculated by dividing the cost responsibility by the corresponding VMTs on that particular facility. Cost responsibilities for all the highway facilities are added to find the combined cost responsibility on all facilities. Combined unit cost for all facilities are calculated by dividing the combined cost responsibility by the total VMT on all highway facilities. The combined unit costs (Figure 4.15) show that among the single-unit trucks (vehicle classes 4 to 7) class 7 and among the multi-unit trucks (vehicle classes 8 to 13) class 11 have the highest unit costs. It should be noted that the first vehicle class in the 20-vehicle class system used in the FHWA HCAS tool consists of both auto and motorcycle (Table 3.8). Therefore, during load related cost allocation the VMTs of motorcycle and autos were combined under the first class, and later the allocated costs were redistributed as per their corresponding VMT shares. This explains the similar unit travel costs for motorcycle (class 1) and passenger cars (class 2) in the FHWA 13 vehicle class system (Figure 4.10 to Figure 4.15).

4.2.2 Pavement Rehabilitation

The cost associated with pavement rehabilitation projects are attributed from two types of sources: load related and non-load related factors. The load related portion accounts for the damage caused by vehicles with different weights, while the non-load related portion accounts for the damage caused by climatic condition (heat, snow, rain, and other factors). The load related portion of the cost is allocated among different classes of vehicles based on VMT and weight distribution. The remaining non-load related portion of the cost is allocated based on VMT by vehicle class. FHWA provides a guideline to distribute the rehabilitation project costs into load and non-load related portion (see Table 4.8) (FHWA, 1997).

Table 4.8: Percentages of pavement rehabilitation costs attributed to load-related factors.

FHWA functional highway class	**Functional highway class for this study**	**Urban**		**Rural**	
		Flexible pavement (%)	**Rigid pavement (%)**	**Flexible pavement (%)**	**Rigid pavement (%)**
Interstate	Interstate	89.0	90.7	89.9	92.1
Other Principal Arterials	US route	87.9	84.3	89.4	89.0
Minor Arterials	NC route	87.8	86.3	88.5	87.2
Major Collectors	Secondary route	85.3	85.5	87.3	83.7
Minor Collectors	N.A.	85.3	85.5	86.1	79.5
Local	N.A.	85.3	85.5	86.1	79.5

Source (FHWA, 1997)

This study adopts four types of highway functional classes: interstate, US, NC and secondary routes. The load related factors for interstate, other principal arterials, minor arterials, and major collectors (Table 4.8) are used for the functional class interstate, US, NC, and secondary routes, respectively.

4.2.2.1 Methodology

Pavement rehabilitation costs are allocated using the National Pavement Cost Model (NAPCOM), which was developed by FHWA as part of the FHWA HCAS (FHWA, 1997). NAPCOM uses two increments: load related costs and non-load related costs of pavement rehabilitation. Pavement damage due to weather and climate conditions, such as heat, snow, rain, and other natural events, is considered non-load related damage.

This cost is distributed among all the vehicle classes according to their VMT. The research team used the FHWA provided factors (FHWA, 1997) to distribute the rehabilitation costs into load and non-load related factors (see Table 4.8).

NAPCOM does not use ESALs to distribute load-related costs. Instead, it includes separate models for different types of distresses in flexible and rigid pavement. For flexible pavement, the method includes individual distress models for fatigue cracking, thermal cracking, rutting, loss of skid resistance, and loss in pavement serviceability rating (PSR) due to traffic and expansive clay. For rigid pavements, the types of distresses introduced in the model include fatigue cracking, spalling, and soil-induced swelling, depression, faulting, loss of skid resistance, and traffic-related PSR loss. These models are used to estimate the rate of progression of individual types of distresses under given pavement design, traffic, and environmental conditions (FHWA, 1997). The coefficients of the NAPCOM model vary for different states. Details of the NAPCOM model can be found in the Appendix A of Idaho Cost Allocation study (Balducci et al., 2010).

The majority of the state HCASs used NAPCOM to allocate the pavement rehabilitation cost. Several studies used the updated 2010 version (ECONorthwest, 2019) or modified version of the NAPCOM to meet the state specific requirements (P Balducci et al., 2009; Tompkins et al., 2012). The 2010 version of the NAPCOM model includes new and updated pavement distress models. This study uses the initial version of the NAPCOM model (FHWA, 2000b, 1997). FHWA HCAS includes state-specific parameters and distress shares for different functional road classes. Due to lack of state-specific information for NC, this study used the default parameters set for the state in the FHWA tool to allocate the pavement rehabilitation project costs. Similar to the new pavement cost allocation, we use NCDOT's WIM data for interstate and US routes and FHWA's default distribution for the other highway routes. In the appendix, section 9.2, we have included both the FHWA and NCDOT WIM distributions.

4.2.2.2 Pavement Rehabilitation Projects

The pavement rehabilitation work includes all the resurfacing projects and surface treatment, preservation, drainage, pavement or bridge widening work, replacement of pavement structures, rest areas, access ramps, and access roads related works under "Other" projects (described in section 4.1.2). We excluded the "Other" projects with work type 4 (signal and signs), 6 (weight station) and some type 5 works that included landscaping, ornamenting, and guardrail installation/maintenance work. Traffic operation related work and landscaping, ornamenting, and guardrail related work under type 5 are allocated based on VMT, while type 6 projects (weight stations) are distributed to truck classes only (FHWA vehicle classes 4-13).

A total of 1,413 pavement related rehabilitation projects were conducted in NC from 2014 to 2017. The project costs were distributed among the four highway classes based on the location descriptions. One hundred and thirteen of these projects' description did not include any information about the facility type of the project. These projects were classified under "Mixed" facility. Table 4.9 shows the total cost by facility from 2014 to 2017 for pavement rehabilitation projects.

Table 4.9: Costs ($Millions) by year and facility type for pavement rehabilitation projects.

	Interstate	US	NC	SR	Mixed	Total by year
2014	19.40	142.03	59.27	313.95	4.10	538.74
2015	84.91	143.22	219.45	311.65	12.42	771.64
2016	58.74	233.25	97.41	401.95	34.35	825.70
2017	88.14	117.99	126.27	339.07	28.64	700.11
Average by year	62.80	159.12	125.60	341.65	19.88	709.05
Total by facility	251.18	636.49	502.40	1,366.61	79.51	2,836.19

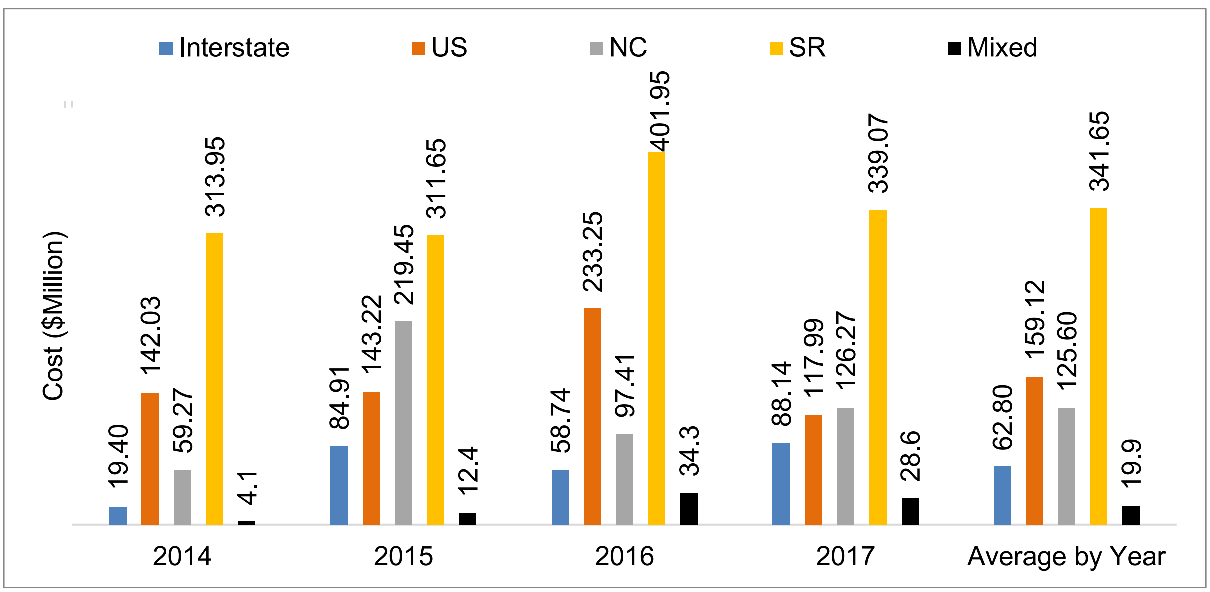


Figure 4.16: Total costs ($Million) by year and facility type for pavement rehabilitation projects.

From Table 4.9, we see that the total cost in pavement rehabilitation projects approached $2.84 billion from 2014 to 2017. Figure 4.16 shows the pavement rehabilitation cost distribution on the four highway facilities from 2014 to 2017. The largest share of pavement rehabilitation projects was carried out on secondary routes, with a total of 773 of the 1413 projects costing an average $341.7 million per year and $1.77 million per project. Interstate had the lowest share of rehabilitation cost (not considering the mixed facility projects), with $62.8 million per year and $3.22 million per project.

It should be mentioned that from the details provided about the rehabilitation projects, the research team could not figure out the type of pavement facility i.e., whether they were done on flexible or rigid pavements. The project details also did not include the area type, i.e., whether they were carried out on urban or rural highway facilities. Therefore, the research team had to approximate before using the factors described in Table 4.8 to allocate the load related costs as per the NAPCOM model. The research team used the county information under the project description to label projects as urban or rural using the latest definition from the state government (NC.gov, 2015). One out of 11 (9%) new pavement projects on NC routes and one out of four (25%) new pavement projects in interstate routes were rigid pavement. Rigid pavement cost 43.5% and 70.4% of the new pavement project costs on interstate and NC routes, respectively. These values, however, will overrepresent the rehabilitation costs for rigid pavements, as this pavement type requires less maintenance work than flexible pavement does. Therefore, the research team used the average of rigid and flexible percentages to find the load related portions of rehabilitation work. Additionally, the first four functional classes described in Table 4.8 (interstate, other principal arterials, minor arterials, and major collectors) were used as representative of interstate, US, NC, and state routes, respectively. For mixed routes, the average of US, NC, and SRs was used. Table 4.10 presents the load and non-load related costs of pavement rehabilitation projects.

Table 4.10: Load and non-load related costs ($Millions) by area type and facility type for pavement rehabilitation projects, 2014-2017.

	Type	Total	Load Related	Non-Load Related
Urban	**Interstate**	214.19	190.99	23.20
	US	236.20	206.77	29.43
	NC	246.79	216.31	30.48
	SR	972.93	829.91	143.02
	Mixed	48.43	42.33	6.09
Rural	**Interstate**	37.00	33.34	3.66
	US	400.29	357.70	42.59
	NC	255.61	225.89	29.73
	SR	393.69	343.69	50.00
	Mixed	31.08	27.57	3.51

4.2.2.3 Pavement Rehabilitation Cost Allocation Results

The non-load related costs of the four types of highway facilities and the mixed facility are distributed according to the VMTs and reported in Table 4.11.

Table 4.11: Cost responsibility ($) by facility type and vehicle class for non-load related pavement rehabilitation projects, 2014-2017.

Vehicle Class		Interstate	US	NC	SR	Mixed	All Facility	All Facility (%)
MC	1	110,949	370,824	337,236	1,527,095	57,947	2,404,052	0.66%
Cars	2	19,720,956	53,731,095	44,946,430	139,850,840	7,112,527	265,361,848	73.36%
2A4T	3	4,099,331	12,871,846	11,116,470	37,818,181	1,779,432	67,685,260	18.71%
Bus	4	134,931	401,562	328,334	1,815,551	62,934	2,743,312	0.76%
2ASU	5	502,910	1,690,087	1,446,768	5,545,350	240,622	9,425,737	2.61%
3ASU	6	154,801	432,331	352,900	1,588,672	62,888	2,591,593	0.72%
4ASU	7	7,589	53,923	40,477	123,310	6,667	231,967	0.06%
4AST	8	167,561	509,106	396,402	1,236,936	64,663	2,374,668	0.66%
5AST	9	1,869,947	1,783,607	1,129,713	3,108,295	196,604	8,088,166	2.24%
6AST	10	24,376	106,114	79,056	304,751	13,909	528,205	0.15%
5AMT	11	37,172	34,915	11,579	15,702	2,693	102,062	0.03%
6AMT	12	17,035	13,567	5,209	10,181	1,138	47,131	0.01%
7AMT	13	3,982	22,160	15,572	73,470	2,985	118,168	0.03%
Total Cost		26,851,542	72,021,136	60,206,146	193,018,334	9,605,010	361,702,168	100%

For the load related costs, this study used the NAPCOM model provided with FHWA HCAS tool. The FHWA NAPCOM model allocates load related costs among 20 types of vehicles, starting from passenger cars and motorcycles to tractor-triple semitrailers. We used the VMT distribution in Table 3.9 to allocate the rehabilitation costs using the NAPCOM model. For mixed routes, we allotted a portion of the VMT from US, NC, and SR routes to mixed routes. The expenditure data in Table 4.10 shows that the expenditures on mixed routes are 12.5%, 15.8%, and 5.8% of the expenditures on US, NC, and SR routes, respectively, thus we allotted 12.5%, 15.8%, and 5.8% of the VMT on US, NC, and SR routes, respectively, to mixed routes for cost allocation purposes. The FHWA HCAS tool also requires separate input for flexible and rigid pavement facility. But, as mentioned earlier, the project details did not include the type of rehabilitation work (flexible or rigid). Therefore, this study used a split of 90% - 10% for flexible and rigid pavement related rehabilitation expenditures on interstate, US, and NC routes based on expert opinion. All the rehabilitation projects on SRs were considered flexible pavement.

Table 4.12 presents the rehabilitation costs allocated among the 13 FHWA vehicle classes. We used the NCDOT's WIM distribution to allocate the costs to interstate and

US routes and FHWA's default WIM distribution to allocate the costs to other highway routes. Table 4.13 presents the total cost responsibilities (load and non-load related) of different vehicle or highway user groups on different highway facilities. Table 4.14 presents the cost responsibility in $/VMT for the FHWA vehicle classes.

Table 4.12: Cost responsibility ($Millions) by facility type and vehicle class for load related pavement rehabilitation projects, 2014-2017.

Vehicle Class		Interstate	US	NC	SR	Mixed	All Facility	All Facility (%)
MC	1	0.08	0.47	0.31	1.04	0.08	1.97	0.08%
Cars	2	13.73	67.89	41.03	95.29	9.32	227.27	9.18%
2A4T	3	5.73	33.75	21.62	58.10	3.73	122.93	4.97%
Bus	4	2.76	12.59	16.25	80.34	2.73	114.68	4.63%
2ASU	5	2.37	15.48	54.85	172.41	8.15	253.26	10.23%
3ASU	6	3.64	22.02	21.22	82.78	3.38	133.03	5.38%
4ASU	7	0.84	10.77	4.19	10.31	0.60	26.71	1.08%
4AST	8	4.07	26.32	24.64	61.97	3.46	120.45	4.87%
5AST	9	182.48	336.56	233.18	521.01	34.50	1,307.73	52.85%
6AST	10	2.35	23.67	16.39	59.94	2.52	104.88	4.24%
5AMT	11	3.99	6.09	2.29	3.17	0.44	15.98	0.65%
6AMT	12	1.33	1.87	1.05	2.27	0.18	6.69	0.27%
7AMT	13	0.96	6.98	5.18	24.96	0.82	38.90	1.57%
Total Costs		224.33	564.47	442.20	1,173.59	69.90	2,474.49	100%

Table 4.13: Cost responsibility ($Millions) by facility type and vehicle class for pavement rehabilitation projects, 2014-2017.

Vehicle Class		Interstate	US	NC	SR	Mixed	All Facility	All Facility (%)
MC	1	0.19	0.84	0.65	2.57	0.13	4.37	0.15%
Cars	2	33.45	121.62	85.98	235.15	16.43	492.63	17.37%
2A4T	3	9.83	46.62	32.73	95.92	5.51	190.61	6.72%
Bus	4	2.90	13.00	16.58	82.15	2.79	117.42	4.14%
2ASU	5	2.88	17.17	56.30	177.95	8.39	262.69	9.26%
3ASU	6	3.79	22.46	21.57	84.37	3.44	135.63	4.78%
4ASU	7	0.85	10.82	4.24	10.43	0.61	26.95	0.95%
4AST	8	4.24	26.83	25.03	63.20	3.52	122.83	4.33%
5AST	9	184.35	338.34	234.31	524.12	34.70	1,315.82	46.39%
6AST	10	2.37	23.78	16.47	60.25	2.53	105.41	3.72%
5AMT	11	4.03	6.13	2.30	3.19	0.44	16.09	0.57%
6AMT	12	1.35	1.88	1.05	2.28	0.18	6.74	0.24%
7AMT	13	0.96	7.00	5.19	25.03	0.83	39.02	1.38%
Total Costs		251.18	636.49	502.40	1,366.61	79.51	2,836.19	100%

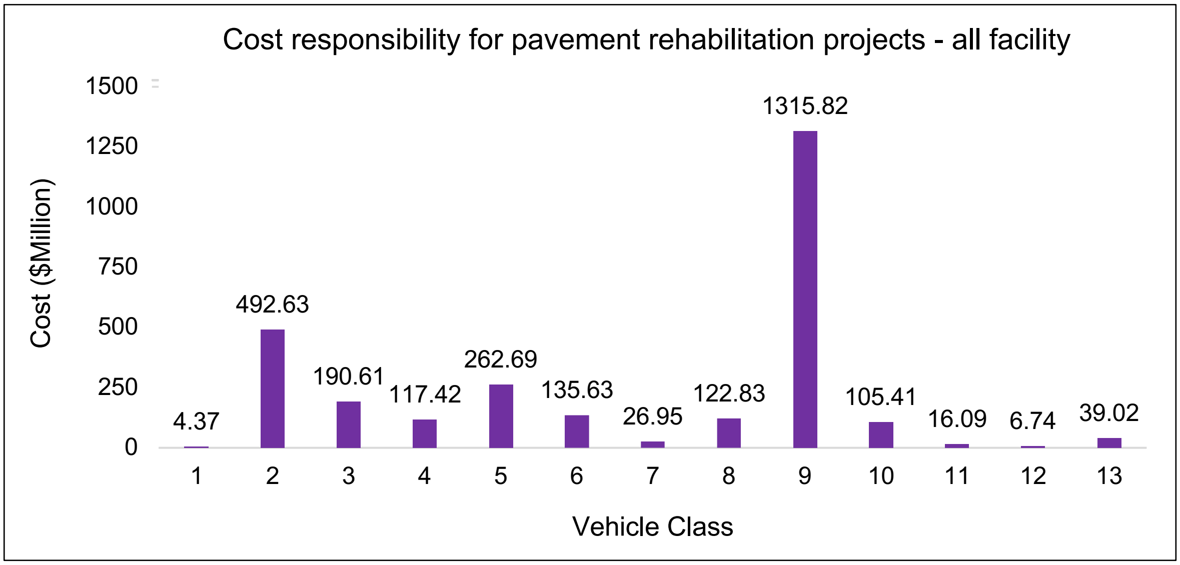


Figure 4.17: Cost responsibility ($Millions) for pavement rehabilitation projects on all facility, 2014-2017.

Table 4.14 presents the cost responsibilities in $/VMT units from all load and non-load related pavement rehabilitation project costs. Figure 4.18 through Figure 4.22 show the unit cost in $/VMT for interstate, US, NC, secondary and mixed routes, respectively, and Figure 4.23 shows the unit cost combined for all facilities.

Table 4.14: Unit cost ($/VMT) by facility type and vehicle class for pavement rehabilitation projects, 2014-2017.

Vehicle Class		Interstate	US	NC	SR	Mixed	All Facility
MC	**1**	0.0005	0.0017	0.0017	0.0021	0.0006	0.0015
Cars	**2**	0.0005	0.0017	0.0017	0.0021	0.0006	0.0015
2A4T	**3**	0.0006	0.0027	0.0027	0.0031	0.0008	0.0023
Bus	**4**	0.0057	0.0242	0.0461	0.0558	0.0119	0.0377
2ASU	**5**	0.0015	0.0076	0.0355	0.0396	0.0093	0.0236
3ASU	**6**	0.0065	0.0389	0.0558	0.0655	0.0147	0.0442
4ASU	**7**	0.0299	0.1502	0.0955	0.1043	0.0246	0.0999
4AST	**8**	0.0067	0.0394	0.0576	0.0630	0.0146	0.0411
5AST	**9**	0.0263	0.1419	0.1893	0.2078	0.0476	0.0947
6AST	**10**	0.0259	0.1677	0.1902	0.2437	0.0489	0.1703
5AMT	**11**	0.0289	0.1313	0.1815	0.2501	0.0447	0.0726
6AMT	**12**	0.0211	0.1037	0.1843	0.2761	0.0435	0.0672
7AMT	**13**	0.0643	0.2364	0.3043	0.4200	0.0743	0.2948

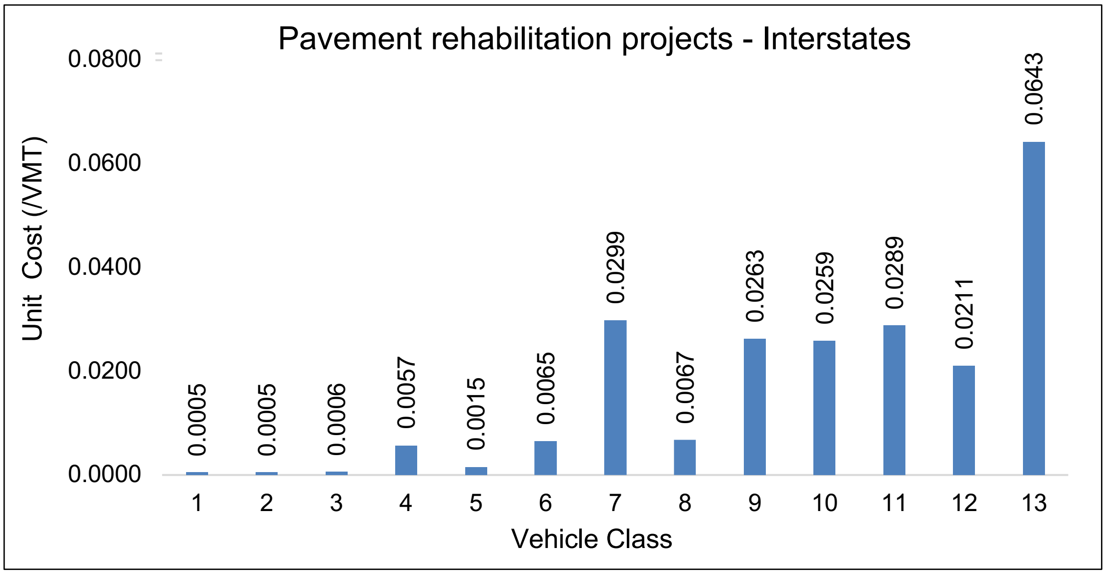


Figure 4.18: Unit cost ($/VMT) for pavement rehabilitation projects on interstates, 2014-2017.

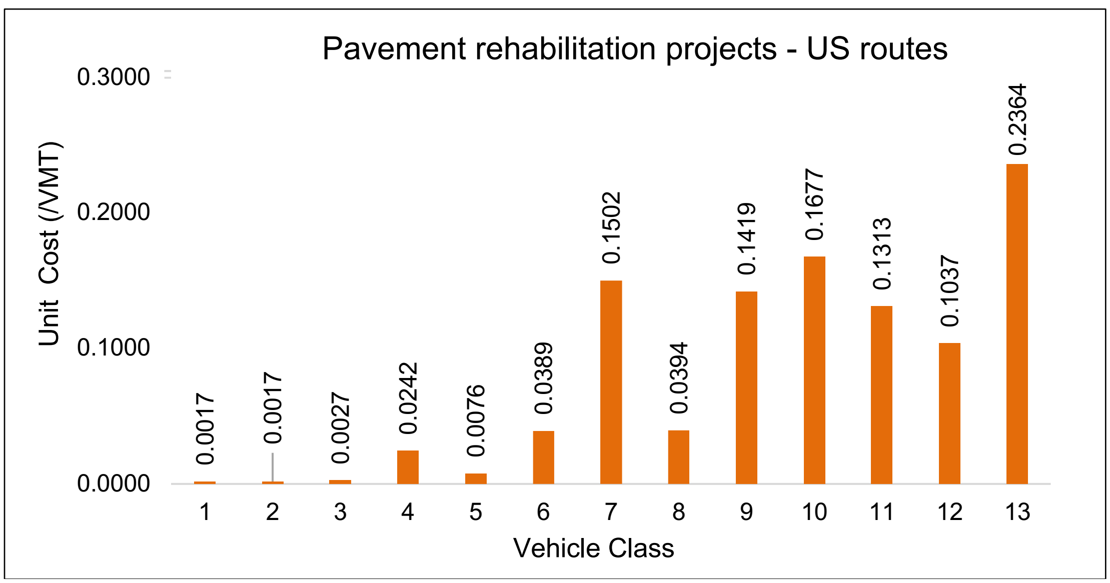


Figure 4.19: Unit cost ($/VMT) for pavement rehabilitation projects on US routes, 2014-2017.

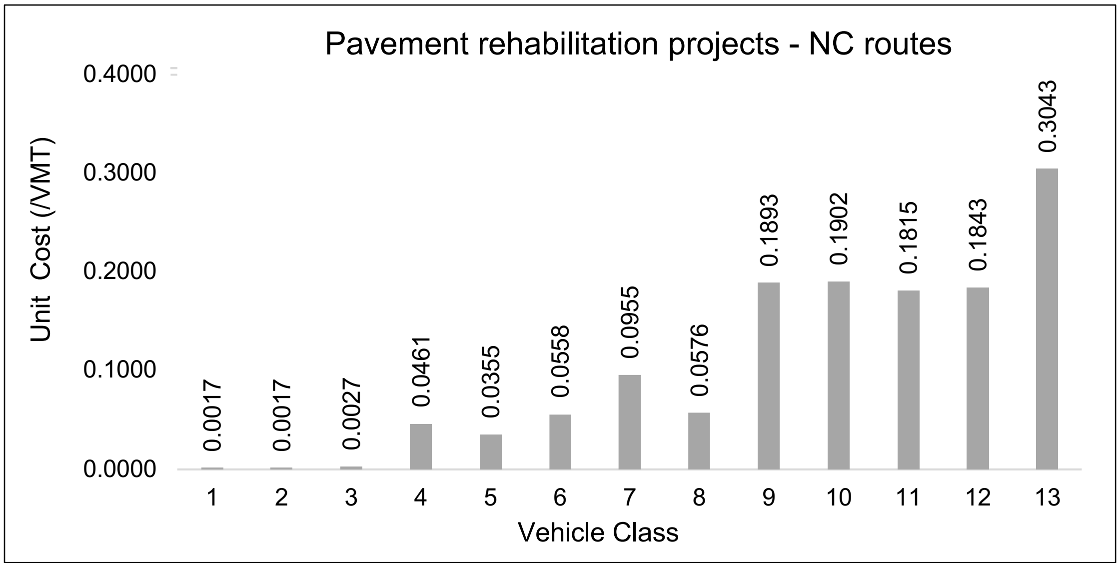


Figure 4.20: Unit cost ($/VMT) for pavement rehabilitation projects on NC routes, 2014-2017.

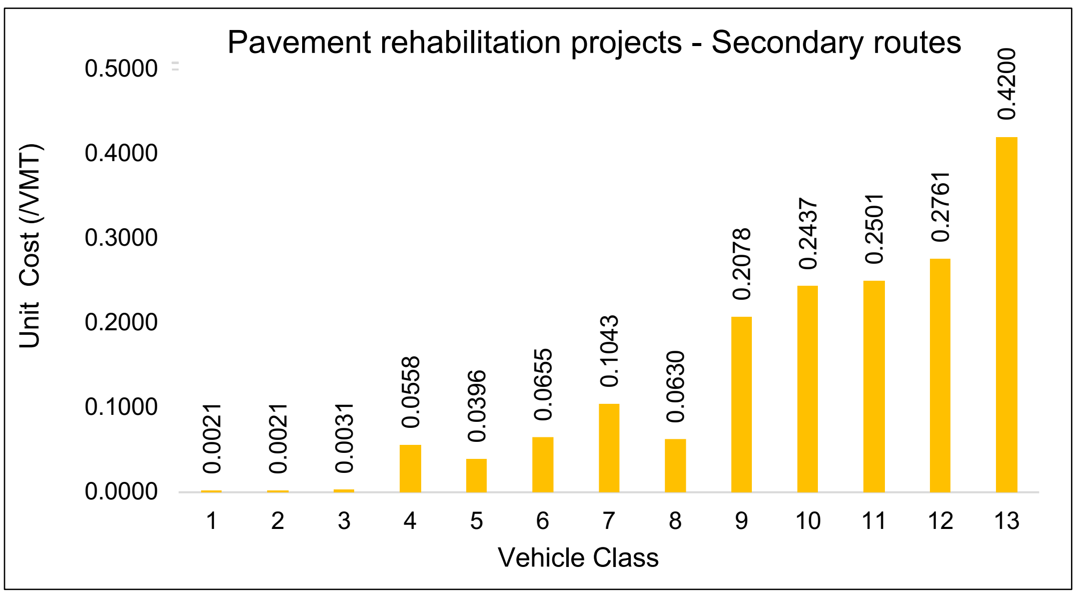


Figure 4.21: Unit cost ($/VMT) for pavement rehabilitation projects on Secondary routes, 2014-2017.

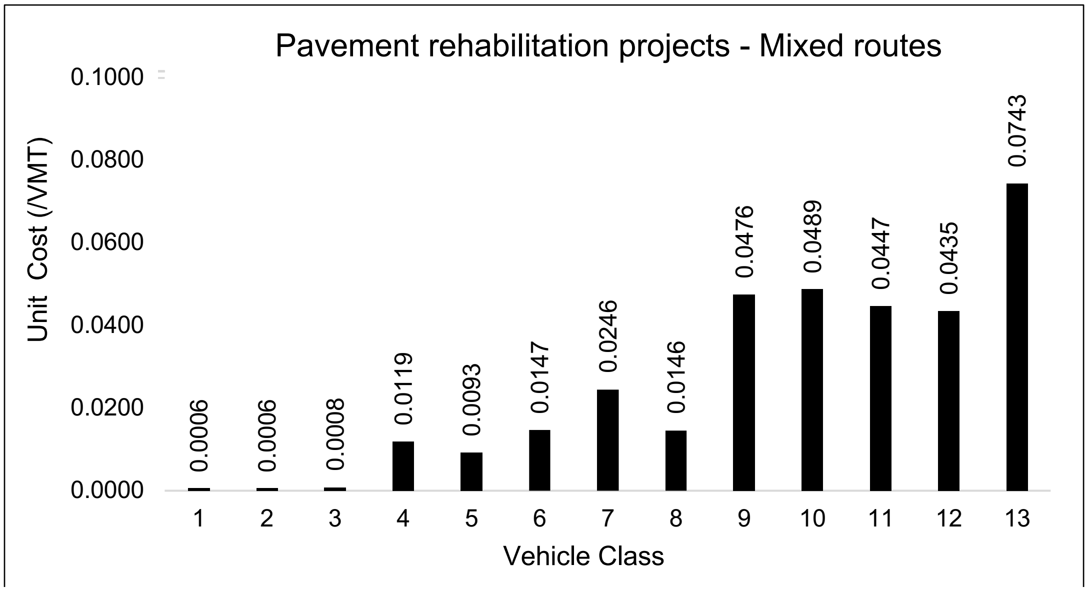


Figure 4.22: Unit cost ($/VMT) for pavement rehabilitation projects on Mixed routes, 2014-2017.

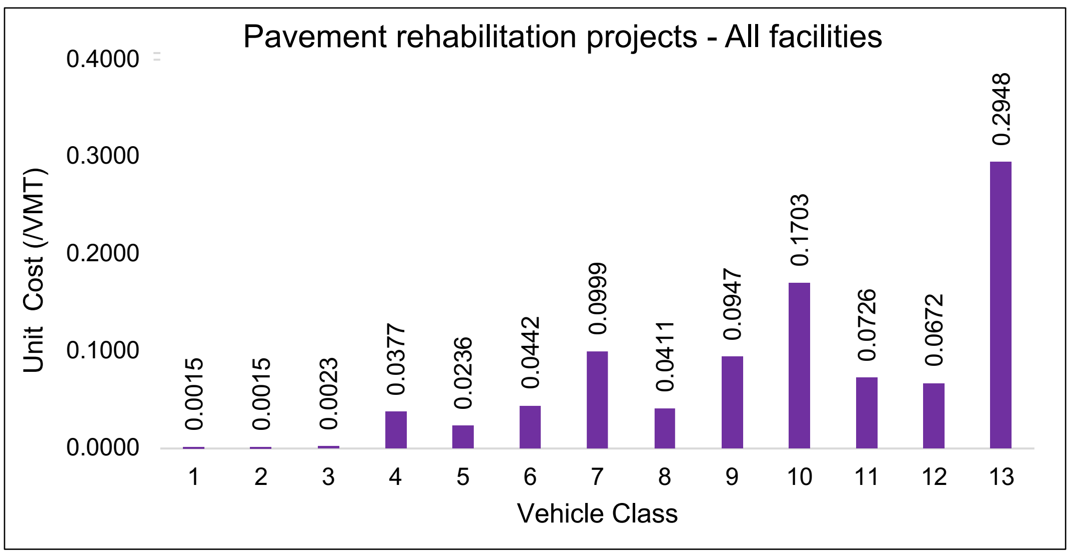


Figure 4.23: Unit cost ($/VMT) for pavement rehabilitation projects on all highway facilities, 2014-2017.

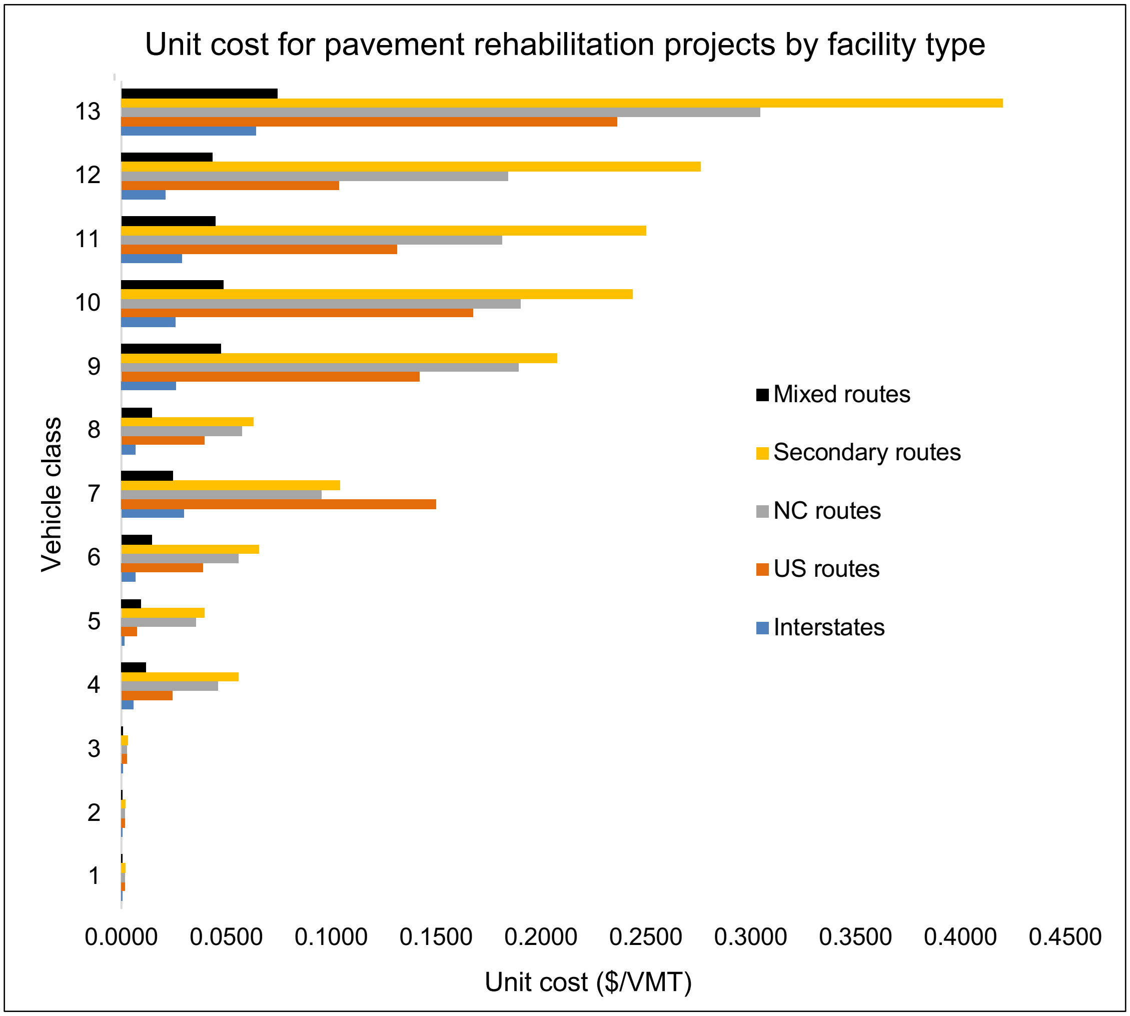


Figure 4.24: Unit cost ($/VMT) for pavement rehabilitation projects by facility type, 2014-2017.

From Table 4.14 and Figure 4.18 through Figure 4.22, we see that the highest unit cost is associated to vehicle class 13 for all types of highway facilities. The combined unit cost for all facilities (Figure 4.23) shows that among the single-unit trucks (vehicle class 4 to 7), class 7 vehicles have the higher unit cost. It should be noted that the first vehicle class in the 20-vehicle class system used in FHWA HCAS tool consists of both auto and motorcycle (Table 3.8). Therefore, during load related cost allocation, the VMTs of motorcycle and autos were combined under the first class, and later the allocated costs were redistributed as per their corresponding VMT shares. This explains the similar unit travel costs for motorcycle (class 1) and autos (class 2) in FHWA 13 vehicle class system (Figure 4.18 to Figure 4.22).

4.2.3 In-house Pavement Maintenance

NCDOT's in-house maintenance projects can be broadly categorized under pavement related, bridge related, and other in-house maintenance work. Facilities on which this maintenance work was carried out include interstate, primary, secondary, ferry, non-system, and state parks. The total costs on all the in-house maintenance projects from 2014 to 2017 was $1.56 billion. We excluded the expenditures for ferry, non-system, and those listed as "N/A" and kept the expenditures for the highway system. The total cost for in-house maintenance projects on highway facilities was $1.54 billion. We used the information listed under the "Project Subtype Name" and "Work Function Name" to categorize projects as pavement related and bridge related projects. Pavement and bridge related in-house maintenance costs were $1.36 billion and $158 million, respectively. The expenditures listed under primary roads were distributed among the US and NC routes. We assigned route types using a 40:60 ratio because, on average, 40% of the combined US and NC route-miles are US routes and 60% are NC routes. The costs listed under "All (Any Division of Highway Road System)" were distributed as per the share of route-miles of interstate, US, NC and secondary routes. Table 4.15 reports the expenditures for different pavement related in-house maintenance work by type of facility. Table 4.16 summarizes the total pavement related in-house maintenance costs by year and facility type.

Table 4.15: Pavement related in-house maintenance costs ($) by facility type, 2014-2017.

System Name	Assigned Facility	Expenditure ($)
All (Any DOH Rd Syst)	All four facilities as per route mile	2,231,842
Interstate	Interstates	50,932,449
Primary	US and NC routes	4,866,121
Primary Paved	US and NC routes	387,482,495
Primary Unpaved	US and NC routes	206,310
Secondary	Secondary routes	50,614,324
Secondary Paved	Secondary routes	819,074,817
Secondary Unpaved	Secondary routes	39,922,978
	Total	1,355,331,336

Table 4.16: Total costs ($Millions) by year and facility type for pavement related in-house maintenance projects.

	Interstate	US	NC	Secondary	Total by Year
2014	13.05	44.01	67.07	228.94	353.07
2015	12.09	40.13	61.16	225.13	338.52
2016	13.26	37.15	56.62	226.42	333.45
2017	12.60	34.52	52.61	230.55	330.29
Total by facility	51.00	155.82	237.46	911.05	**1,355.33**
Average yearly on facility	12.75	38.95	59.37	227.76	

As seen in Table 4.16, from 2014 to 2017 pavement related in-house maintenance expenditure was almost $1.36 billion.

The types of maintenance work conducted by the NCDOT include asphalt overlay, asphalt patching, grading, drainage, shoulder repair, pavement markings and signs, landscaping, sealing, slope protection, traffic control devices, ITS setup, and others. This maintenance is categorized under 11 subtypes: bridge program, disaster, guard rail, pavement preservation, resurfacing, snow and ice, standing, system preservation, turnpike, urban, and other (statewide). The resurfacing work here represents the smaller resurfacing projects not delegated to external contractors.

HCAS studies for other states used different methods to distribute the in-house maintenance costs among users. Indiana first divided the total costs into load and non-load related portions using factors (see Table 4.17) proposed by a previous study done in Indiana (Sinha et al., 1984). Then, they divided the non-load related costs per VMT and load related costs per ESAL-miles, as ESALs account for the vehicle class distribution as well as the load equivalent factors (Volovski et al., 2015). One ESAL-mile is equivalent to one single axle load traveling over one mile.

Table 4.17: Load-related cost factors for in-house maintenance projects. (*Source:* (Sinha et al., 1984)

	Flexible Pavement (%)	**Rigid Pavement (%)**
Northern Indiana	87	66
Southern Indiana	98	70
Average	92	68

Similar studies are not available for NCDOT's in-house maintenance data. Oregon used either VMT or ESAL-miles, depending on the types of maintenance work, to distribute the costs among the users (ECONorthwest, 2019). The documentation provided with the FHWA HCAS tool includes basis of allocating the maintenance expenditure using vehicle characteristics and the types of maintenance work (FHWA, 2000a). In FHWA HCAS documentation, the majority of expenditures for the most types of the maintenance are distributed as per the VMTs, considering them as part of common costs (FHWA, 2000a). The guideline also suggested distributing a portion (20% to 50%) of the work involving resurfacing, sealing, base repair, and preservation as per ESAL miles, considering them load related expenditures.

In this study, we considered load-related factors from Sinha et al., (1984), as shown in Table 4.17, to split the costs of in-house pavement maintenance projects with subtypes “Pavement Preservation,” “System Preservation,” and “Resurfacing” into load and non-load related portions. Like pavement rehabilitation projects, we considered 90:10 split for flexible and rigid pavement related costs, respectively. For bridge related in-house maintenance proejcts, we considered 50% of the total costs for subtype “Bridge Program” and “System Preservation” as load-related expenditures. Load-related costs were allocated using the FHWA HCAS tool using the same procedure as pavement rehabilitation cost allocation. This calculation required the area types (i.e., urban or rural) where the projects were completed. Unfortunately, descriptions of the in-house maintenance projects do not include location descriptions that the research team could use to estimate the area types. Therefore, the research team used the average urban and rural shares from the pavement rehabilitation projects to divide the in-house pavement maintenance costs into urban and rural area types. The remaining costs from these subtypes and 100% costs of all the other subtypes are considered common costs and thus were distributed per the VMTs of the vehicles. Table 4.18 below presents the load and non-load related cost shares for the four highway facilities from pavement related in-house maintenance projects.

Table 4.18: Load and non-load related cost shares ($) by facility type for pavement related in-house maintenance projects, 2014-2017.

Pavement facility		**Interstate**	**US**	**NC**	**SR**
Rigid pavement	**Load-related**	5,398	1,114,988	1,699,213	0
	Non-load related	5,094,735	14,466,927	22,047,274	0
Flexible pavement	**Load-related**	66,085	13,650,400	20,802,862	185,409,534
	Non-load related	45,835,114	126,586,831	192,915,515	725,636,461
Total by facility		51,001,332	155,819,146	237,464,864	911,045,995

Table 4.19 through Table 4.21 present the cost shares of the 13 FHWA vehicle classes for pavement in-house maintenance expenditures from 2014 to 2017. Table 4.22 shows the unit cost shares in $/VMT.

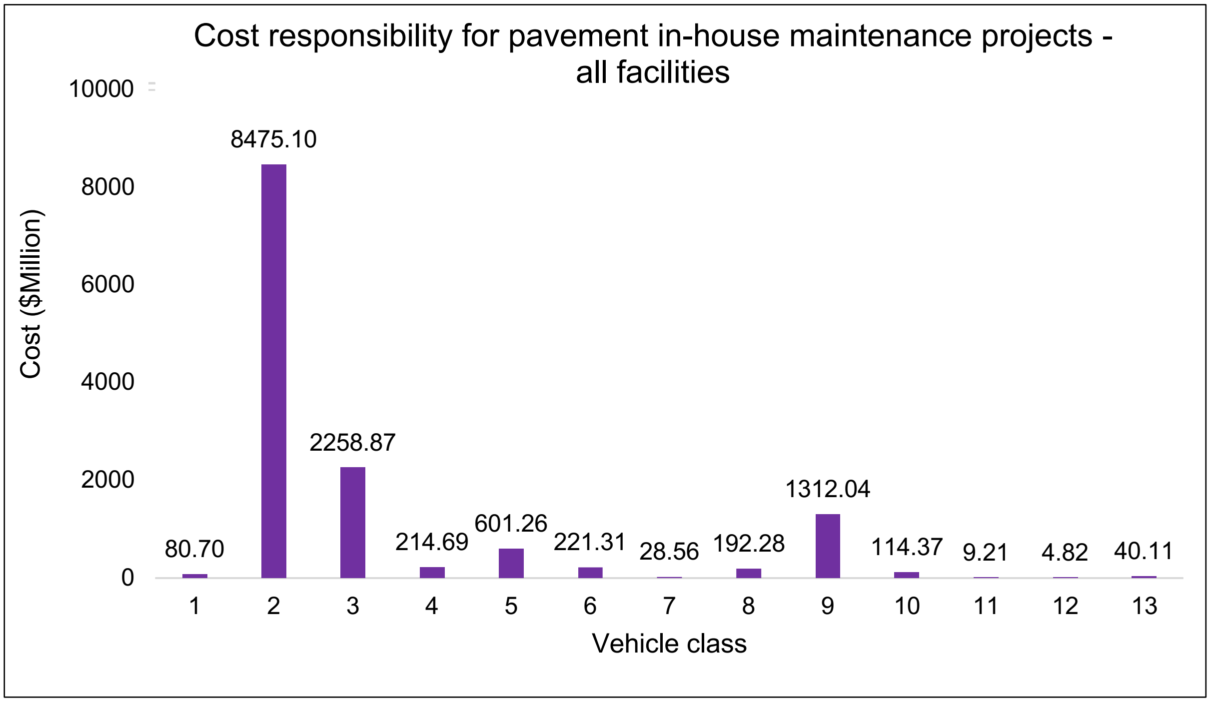


Figure 4.25: Cost responsibility ($Million) for pavement in-house maintenance projects on all facilities, 2014-2017.

Table 4.19: Cost responsibility ($) by facility type and vehicle class for non-load related pavement in-house maintenance projects, 2014-2017.

Vehicle Class		Interstate	US	NC	SR	All Facilities
MC	**1**	210,439	726,261	1,204,084	5,740,988	7,881,772
Cars	**2**	37,405,126	105,232,620	160,478,797	525,757,664	828,874,208
2A4T	**3**	7,775,282	25,209,575	39,690,755	142,174,323	214,849,934
Bus	**4**	255,927	786,460	1,172,300	6,825,412	9,040,100
2ASU	**5**	953,879	3,310,045	5,165,607	20,847,284	30,276,815
3ASU	**6**	293,615	846,723	1,260,011	5,972,482	8,372,831
4ASU	**7**	14,395	105,609	144,522	463,572	728,098
4AST	**8**	317,817	997,086	1,415,332	4,650,159	7,380,393
5AST	**9**	3,546,764	3,493,204	4,033,578	11,685,379	22,758,925
6AST	**10**	46,234	207,825	282,264	1,145,686	1,682,008
5AMT	**11**	70,505	68,382	41,342	59,032	239,261
6AMT	**12**	32,311	26,571	18,599	38,276	115,756
7AMT	**13**	7,553	43,400	55,598	276,204	382,755
Total Cost		50,929,849	141,053,758	214,962,789	725,636,461	1,132,582,857

Table 4.20: Cost responsibility ($) by facility type and vehicle class for load related pavement in-house maintenance projects, 2014-2017.

Vehicle Class		Interstate	US	NC	SR	All Facilities
MC	1	22	13,977	15,715	158,467	188,181
Cars	2	3,902	2,025,260	2,094,421	14,512,332	18,635,915
2A4T	3	1,614	920,796	1,058,211	9,056,816	11,037,436
Bus	4	809	346,335	800,141	11,281,267	12,428,553
2ASU	5	689	417,373	2,723,507	26,707,430	29,849,000
3ASU	6	1,057	633,631	1,043,596	12,079,590	13,757,874
4ASU	7	246	318,338	202,899	1,606,391	2,127,874
4AST	8	1,309	684,882	1,238,731	9,922,474	11,847,396
5AST	9	59,052	8,344,877	12,090,347	87,950,610	108,444,886
6AST	10	775	655,418	814,471	8,284,704	9,755,368
5AMT	11	1,277	158,833	114,585	406,946	681,642
6AMT	12	426	46,835	52,135	267,095	366,491
7AMT	13	305	198,832	253,315	3,175,411	3,627,863
Total Cost		71,483	14,765,388	22,502,074	185,409,534	222,748,479

Table 4.21: Cost responsibility ($Millions) by facility type and vehicle class for pavement in-house maintenance projects, 2014-2017.

Vehicle Class		Interstate	US	NC	SR	All facilities	All facilities (%)
MC	1	0.21	0.74	1.22	5.90	8.07	0.60%
Cars	2	37.41	107.26	162.57	540.27	847.51	62.53%
2A4T	3	7.78	26.13	40.75	151.23	225.89	16.67%
Bus	4	0.26	1.13	1.97	18.11	21.47	1.58%
2ASU	5	0.95	3.73	7.89	47.55	60.13	4.44%
3ASU	6	0.29	1.48	2.30	18.05	22.13	1.63%
4ASU	7	0.01	0.42	0.35	2.07	2.86	0.21%
4AST	8	0.32	1.68	2.65	14.57	19.23	1.42%
5AST	9	3.61	11.84	16.12	99.64	131.20	9.68%
6AST	10	0.05	0.86	1.10	9.43	11.44	0.84%
5AMT	11	0.07	0.23	0.16	0.47	0.92	0.07%
6AMT	12	0.03	0.07	0.07	0.31	0.48	0.04%
7AMT	13	0.01	0.24	0.31	3.45	4.01	0.30%
Total Cost		51.00	155.82	237.46	911.05	1355.33	100.00%

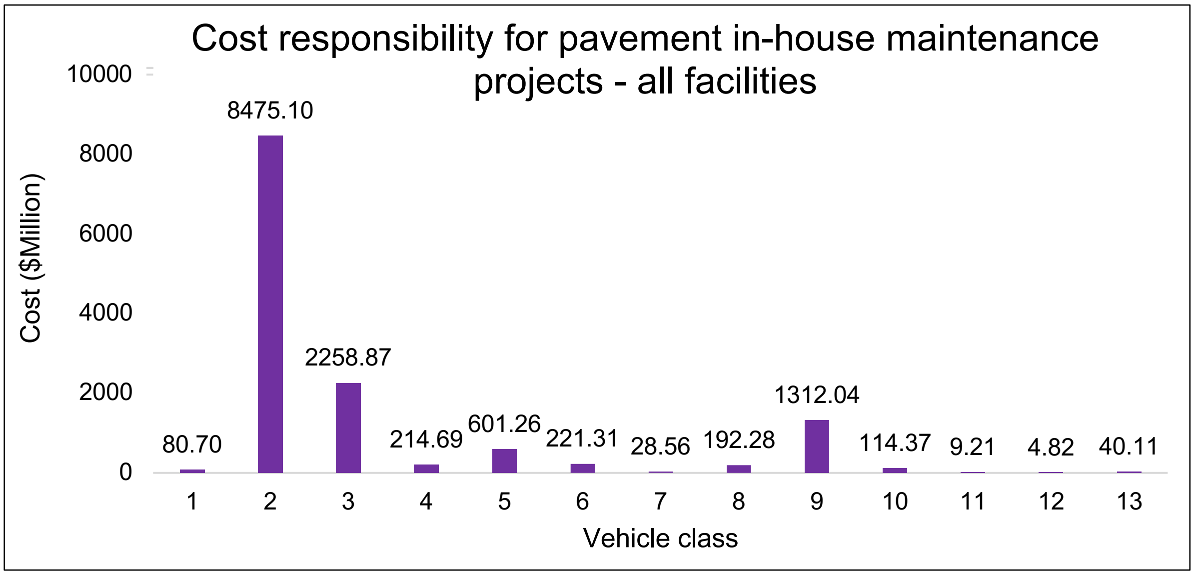


Figure 4.25: Cost responsibility ($Million) for pavement in-house maintenance projects on all facilities, 2014-2017.

Table 4.22: Unit cost ($/VMT) by facility type and vehicle class for pavement in-house maintenance projects, 2014-2017.

Vehicle Class		Interstate	US	NC	SR	All Facility
MC	**1**	0.00051	0.00131	0.00278	0.00448	0.00295
Cars	**2**	0.00051	0.00131	0.00278	0.00448	0.00253
2A4T	**3**	0.00051	0.00133	0.00282	0.00464	0.00275
Bus	**4**	0.00051	0.00185	0.00462	0.01158	0.00690
2ASU	**5**	0.00051	0.00144	0.00419	0.00996	0.00540
3ASU	**6**	0.00051	0.00224	0.00502	0.01319	0.00721
4ASU	**7**	0.00051	0.00515	0.00659	0.01949	0.01059
4AST	**8**	0.00051	0.00216	0.00514	0.01368	0.00643
5AST	**9**	0.00051	0.00435	0.01097	0.03721	0.00944
6AST	**10**	0.00051	0.00533	0.01066	0.03592	0.01848
5AMT	**11**	0.00051	0.00426	0.01035	0.03445	0.00416
6AMT	**12**	0.00051	0.00354	0.01043	0.03482	0.00481
7AMT	**13**	0.00053	0.00716	0.01524	0.05454	0.03030

Figure 4.26 through Figure 4.29 show the unit cost in $/VMT for interstate, US, NC, and secondary routes, respectively, and Figure 4.30 shows the unit cost for all highway facilities. Figure 4.31 compares the unit costs of the 13 vehicle classes by highway facility type.

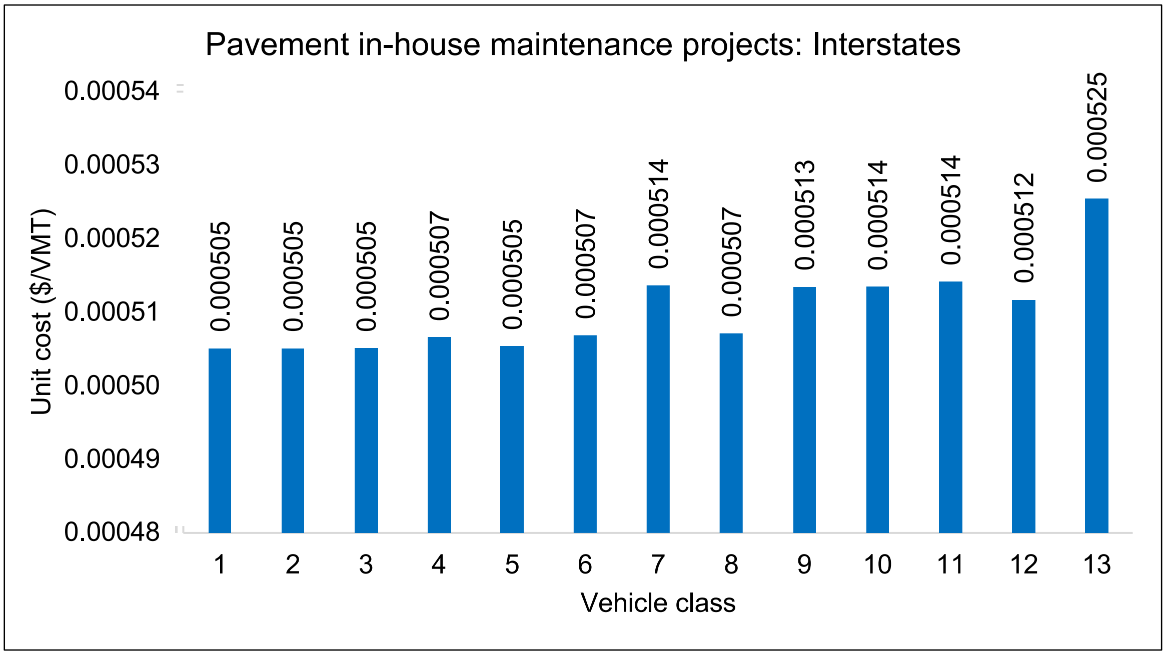


Figure 4.26: Unit cost ($/VMT) for pavement rehabilitation projects on interstates, 2014-2017.

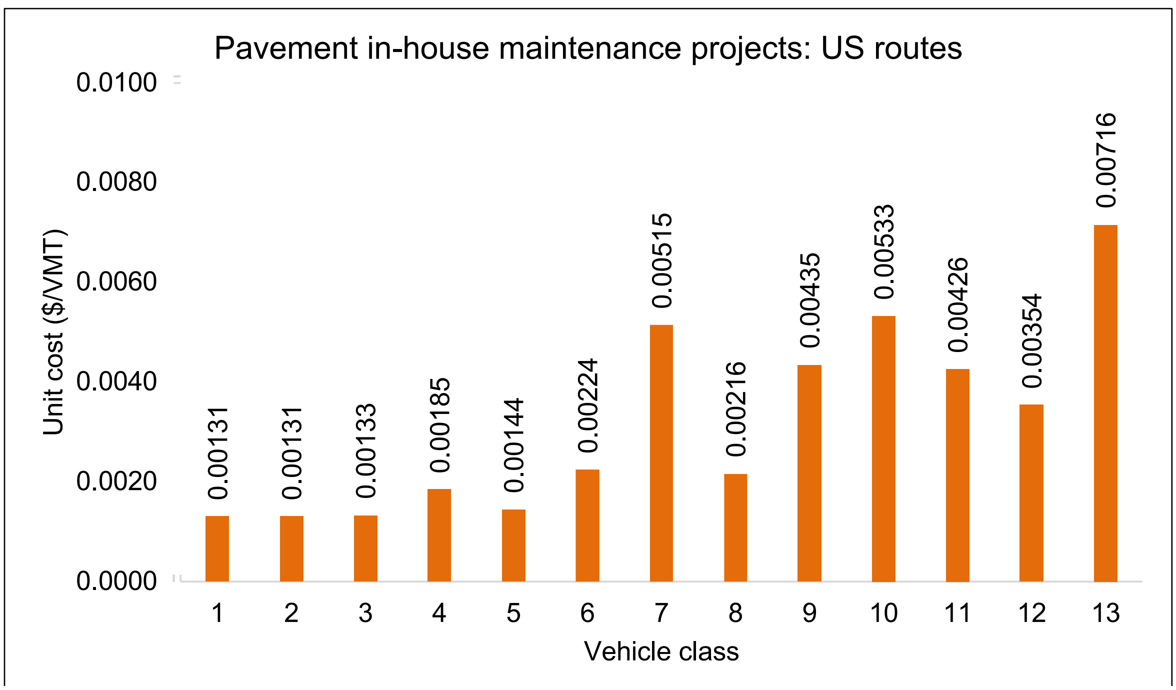


Figure 4.27: Unit cost ($/VMT) for pavement rehabilitation projects on US routes, 2014-2017.

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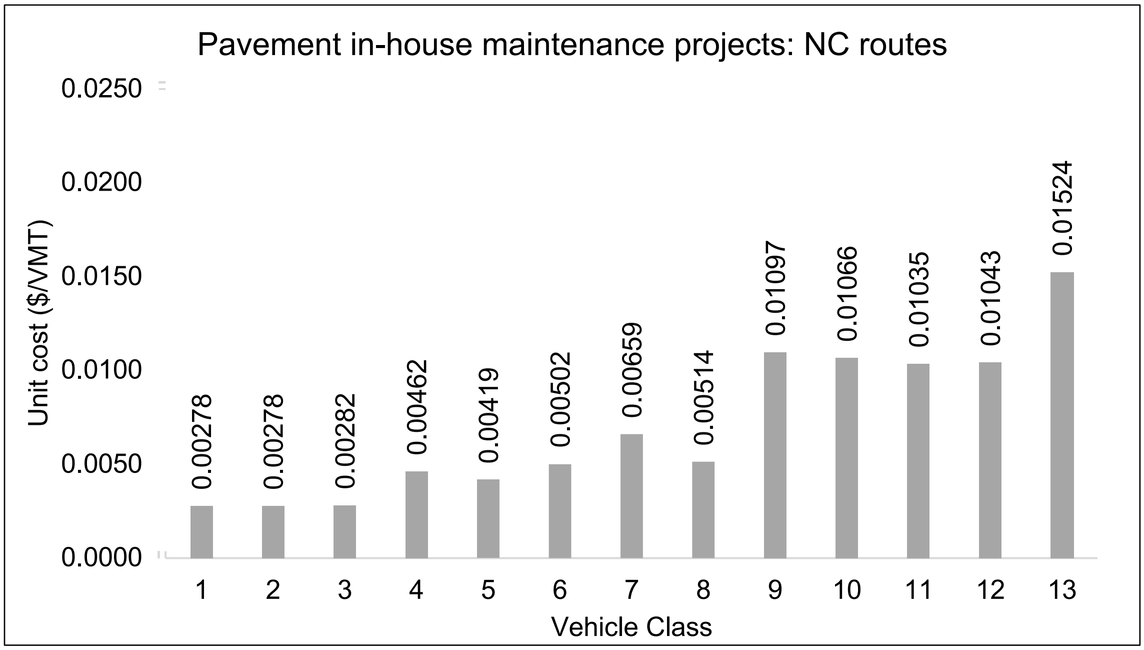


Figure 4.28: Unit cost ($/VMT) for pavement rehabilitation projects on NC routes, 2014-2017.

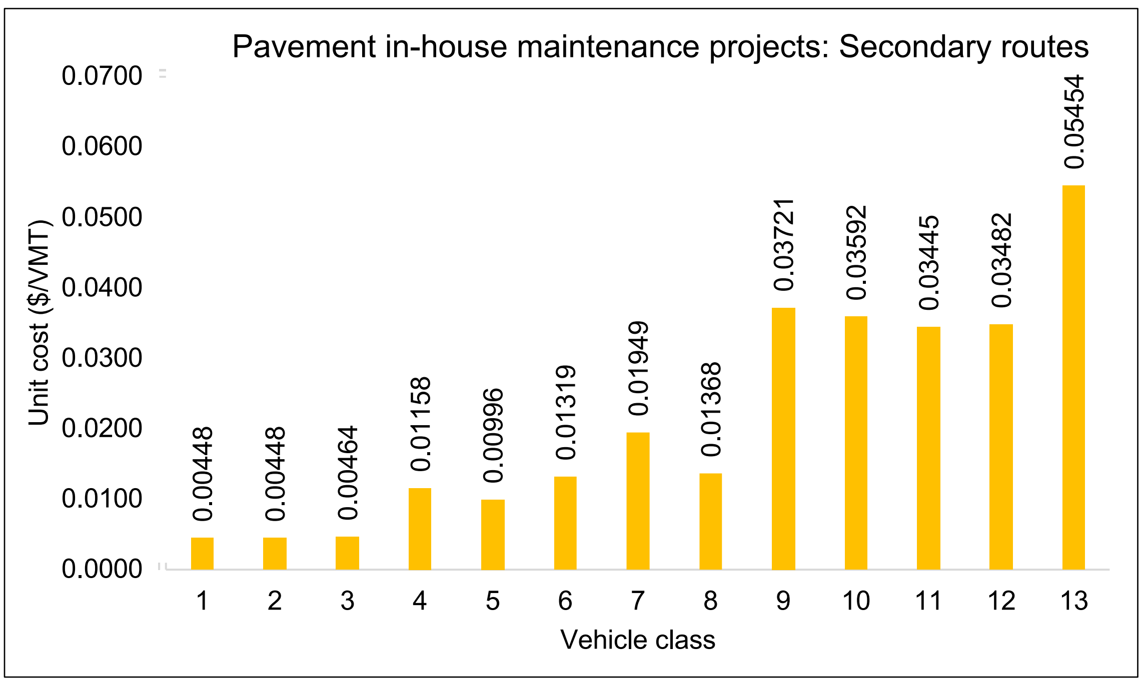


Figure 4.29: Unit cost ($/VMT) for pavement rehabilitation projects on secondary routes, 2014-2017.

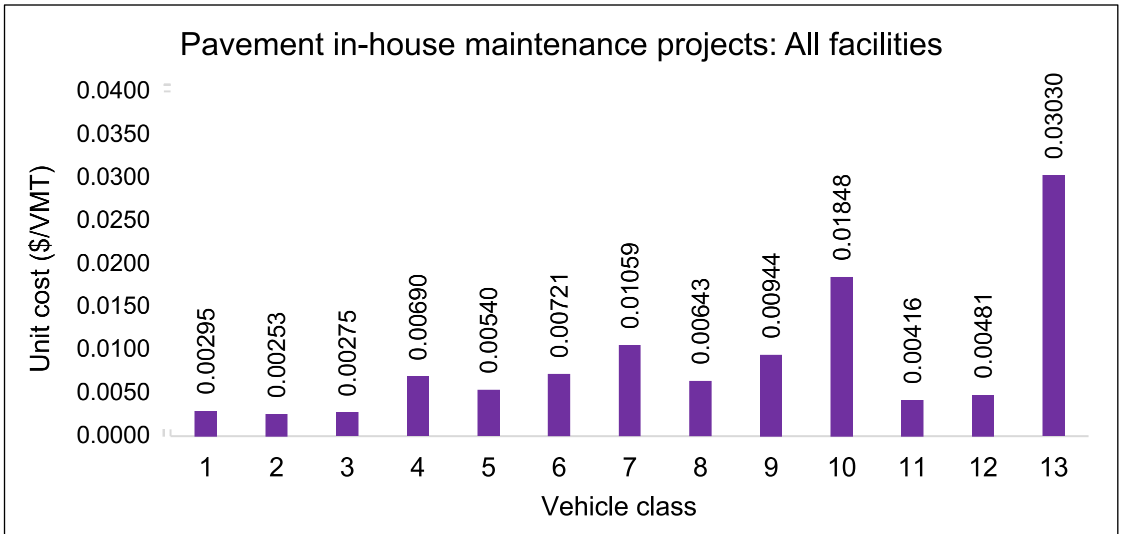


Figure 4.30: Unit Cost ($/VMT) for pavement in-house maintenance on all highway facilities, 2014-2017.

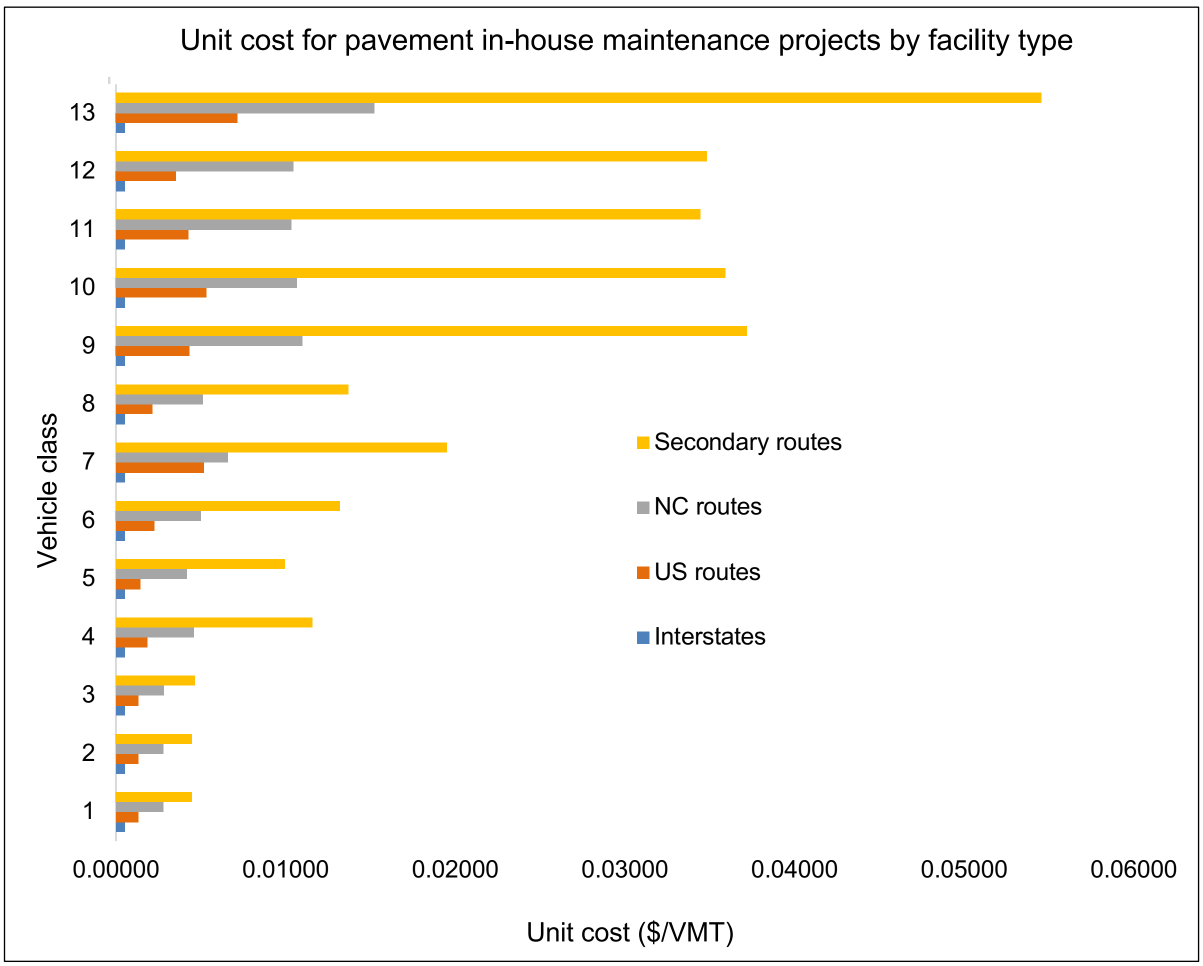


Figure 4.31: Unit cost ($/VMT) by facility type for pavement in-house maintenance projects, 2014-2017.

As seen in Table 4.22 and Figure 4.31, class 13 vehicles have the greatest unit cost on all highway facilities. Additionally, the majority of in-house maintenance work is carried out on secondary routes. Therefore, the cost responsibilities and the unit costs for the vehicle classes are higher on secondary routes compared to other highway facilities.

4.3 Cost Allocation of Bridge-related Project Expenditure

4.3.1 New and Replacement Bridge

4.3.1.1 New and Replacement Bridge Projects

North Carolina completed 71 new bridge construction and replacement projects at a cost of approximately $629.18 million from 2014 to 2017. Besides these 71 projects, some of the mixed type (pavement and bridge) projects have more than 25% of the total costs allocated to bridge related work. Those costs were also included with the new/replacement bridge projects, making the total expenditure $801.3 million. The project locations were included with the description of the new and replacement bridge projects; however, for the facility types (interstate, US, NC, or secondary routes) and the area types (urban or rural), the research team reviewed the Request for Proposals (RFP) documents to determine those. Some bridge projects had several structures at different locations and with different types of facilities. For instance, project number C203046 included replacement works on 12 bridges: 5 in US routes, 5 in NC routes, and 2 in secondary routes. The expenditures of these project types are therefore distributed in proportion of the number of structures on each type of facility. Table 4.23 presents the total expenditures for each year under each type of facility.

Table 4.23: Total costs ($Millions) by year and facility type for new and replacement bridge projects.

Year	Interstate	US	NC	SR	Total by year
2014	162.70	0.00	3.13	15.64	181.48
2015	133.69	20.14	1.36	67.03	222.23
2016	43.29	10.54	14.09	112.88	180.81
2017	0.00	90.15	6.10	120.54	216.79
Total Cost by Facility	339.69	120.84	24.68	316.09	801.30

4.3.1.2 Methodology

The methods described in the federal HCAS guideline (FHWA, 2000a, 1997) were used to allocate the costs of new bridge construction and the cost of bridge replacement projects. The method, developed in 1997, uses incremental analysis for different design loadings to allocate cost increments to the highway users (vehicle classes). The live-load moments from each vehicle class are compared with the design live-load moments to assign the costs. The live-load moment depends on the size, weight, axle-spacing, and distribution of weights among the axles. The first cost increment is associated with the lightest design loading and is shared by all vehicle classes. The subsequent cost increments are shared by the heavier vehicle classes. Stresses produced by each vehicle class are compared with the design loading to estimate the cost responsibilities of each vehicle type (P Balducci et al., 2009). The FHWA HCAS tool includes the fraction of vehicles falling into each bridge design increment, as a function of vehicle configuration and operating weight. Axle weight distribution and spacings from weigh-in-motion data were used to develop these fractions. More information on how the FHWA determined the cost allocation percentage share of cost increments is provided in the guideline document accompanying the FHWA HCAS tool (FHWA, 2000a). This study used the default percent allocation factors, shown in Table 4.24, for HS20 design loads provided with the FHWA HCAS tool (FHWA, 2000a). HS20 loading is used to express the extreme loading effects from heavy moving vehicles such as trucks and buses. HS20 describes loading conditions up to 18-wheeler trucks. It assumes 16 kip wheel load or 32 kip axle load (AASHTO, 2002).

Table 4.24: Percent allocations of New and Replacement Bridge costs (FHWA, 2000a).

Increment	Percent Allocation
All Vehicles	83.19%
H2.5+	4.19%
H5+	2.41%
H10+	3.04%
H15+	2.44%
HS15+	4.73%
HS20+	0.00%
Total	100.00%

The loading increments (H2.5 to HS20) are associated with 20 vehicle classes. The estimated VMT for the 13 FHWA vehicle classes were redistributed to the 20 vehicle classes (see Table 3.9) to use the FHWA HCAS tool for cost allocation of new bridge and replacement bridge work. Other studies, such as the Indiana state HCAS, used correlation factors between the study vehicle weight groups and the AASHTO design loading (Volovski et al., 2015).

For allocating the costs of bridge replacement projects, the percentage of bridge replacements that occur due to structural (load bearing) deficiencies must first be defined. FHWA uses a bridge sufficiency rating formula (FHWA, 1995) to calculate those percentages. FHWA developed sufficiency ratings to prioritize funding for bridge rehabilitation and/or replacement projects (VDOT, 2020). Ratings vary from 0%, indicating poor condition of an existing bridge, to 100%, indicating very good condition of an existing bridge. The sufficiency rating formula considers structural adequacy, functional obsolescence, and level of service provided to the public (VDOT, 2020). The loss of sufficiency points (B) caused by the inadequate load-carrying capacities can be calculated as the function of inventory rating (IR) (FHWA, 2000c; Volovski et al., 2015):

$$B = 0.3254 * (32.4 - IR)^{1.5} \; for \; IR < 32.4$$

$$B = 0 \; otherwise$$

The IR is defined as the load combination in one or multiple lanes that can safely operate on the bridge for an indefinite period of time (AASHTO, 2011). A bridge loses points when its load bearing capacity drops below an adequate level or when it faces other non-load related problems like scouring around piers or being inadequate for current traffic demand. The points lost due to inadequate load bearing capacity are reported as a fraction of total points lost due to all factors. The costs due to the deficit in load bearing capacity of the bridge are allocated to the vehicles with operating weights over the load bearing capacity of the replaced bridge. The sufficiency rating of a bridge is calculated before it is replaced, and the value of (B/sufficiency ratings) indicates the share of the total replacement costs that should be allocated to vehicles with operating weights over the load bearing capacity of the replaced bridge. In this study, the research team used the default percentages provided in FHWA HCAS tool as the sufficiency ratings. IR data were not included with the project descriptions provided by NCDOT. Previous highway cost allocation studies including Indiana (Volovski et al., 2015), Idaho (Balducci et al., 2010), and Nevada (P Balducci et al., 2009) also used the FHWA's sufficiency rating formula to allocate the new and replacement bridge costs. The Minnesota HCAS modified the model to incorporate state specific factors (Gupta and Chen, 2012).

4.3.1.3 New and Replacement Bridge Cost Allocation Results

Table 4.25 presents the costs from New Bridge projects allocated to FHWA 13 vehicle classes on different highway facilities.

Table 4.25: Cost responsibility ($Millions) by facility type for new and replacement bridge projects, 2014-2017.

Vehicle Class		Interstate	US	NC	SR	All Facility	All Facility (%)
MC	1	0.70	0.35	0.06	0.83	1.46	0.18%
Cars	2	124.02	51.18	7.36	76.38	259.42	32.37%
2A4T	3	34.14	15.92	2.43	27.48	79.97	9.98%
Bus	4	5.10	3.82	1.17	28.41	38.50	4.80%
2ASU	5	7.28	4.02	1.34	18.12	30.77	3.84%
3ASU	6	4.11	2.59	0.60	10.14	17.44	2.18%
4ASU	7	0.48	1.06	0.12	1.49	3.15	0.39%
4AST	8	4.89	3.26	0.74	8.61	230.99	28.83%
5AST	9	144.17	30.66	8.04	96.48	45.77	5.71%
6AST	10	2.77	2.92	0.97	16.72	43.45	5.42%
5AMT	11	5.82	1.23	0.36	2.21	9.62	1.20%
6AMT	12	3.02	0.59	0.28	2.55	6.44	0.80%
7AMT	13	3.20	3.24	1.21	26.66	34.32	4.28%
Total Cost		339.7	120.8	24.7	316.1	801.3	100%

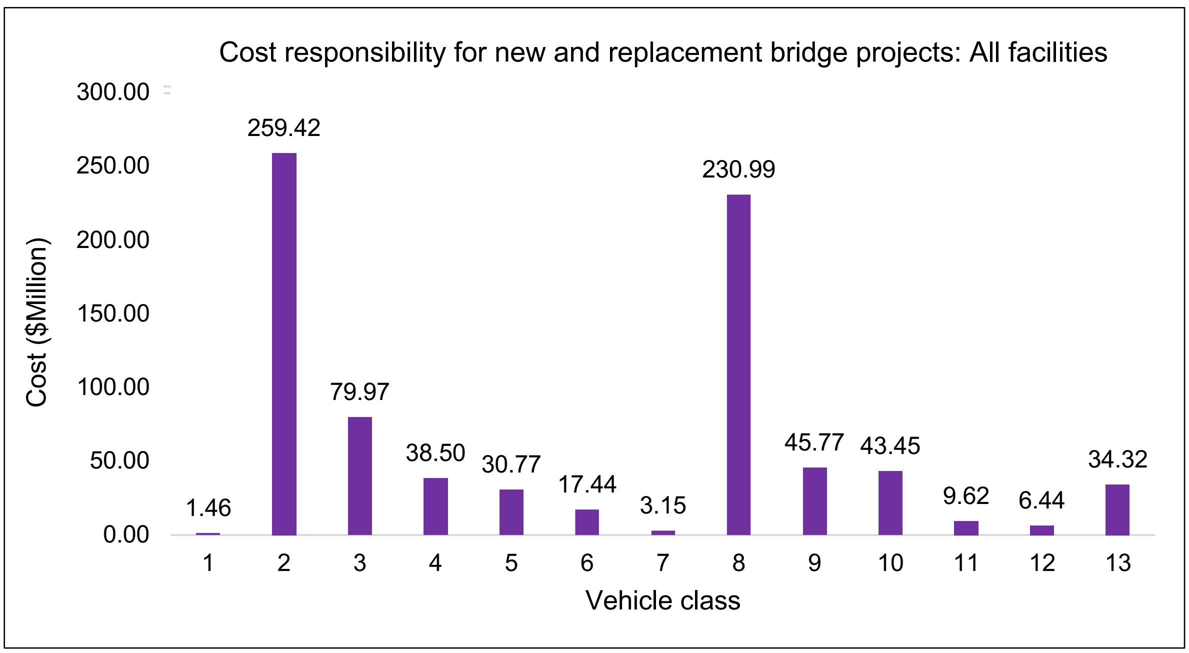


Figure 4.32: Cost responsibility ($Millions) by vehicle class for new and replacement bridge projects on all facilities, 2014-2017.

Table 4.26 presents the cost responsibilities in $/VMT units from all load and non-load related costs from new pavement projects.

Table 4.26: Unit cost ($/VMT) by facility type for new and replacement bridge projects, 2014-2017.

Vehicle Class		Interstate	US	NC	SR	All Facility
MC	1	0.0017	0.0006	0.0001	0.0006	0.0005
Cars	2	0.0017	0.0006	0.0001	0.0006	0.0008
2A4T	3	0.0022	0.0008	0.0002	0.0008	0.0010
Bus	4	0.0101	0.0062	0.0027	0.0182	0.0124
2ASU	5	0.0039	0.0016	0.0007	0.0038	0.0028
3ASU	6	0.0071	0.0039	0.0013	0.0074	0.0057
4ASU	7	0.0168	0.0129	0.0023	0.0141	0.0117
4AST	8	0.0078	0.0042	0.0014	0.0081	0.0773
5AST	9	0.0205	0.0113	0.0055	0.0360	0.0033
6AST	10	0.0302	0.0180	0.0095	0.0637	0.0702
5AMT	11	0.0417	0.0231	0.0236	0.1635	0.0434
6AMT	12	0.0473	0.0286	0.0412	0.2904	0.0643
7AMT	13	0.2139	0.0957	0.0599	0.4213	0.2593

Figure 4.33 through Figure 4.36 show the unit cost in $/VMT for interstate, US, NC, secondary, and mixed routes, respectively, and Figure 4.37 shows the unit cost for all the facility types.

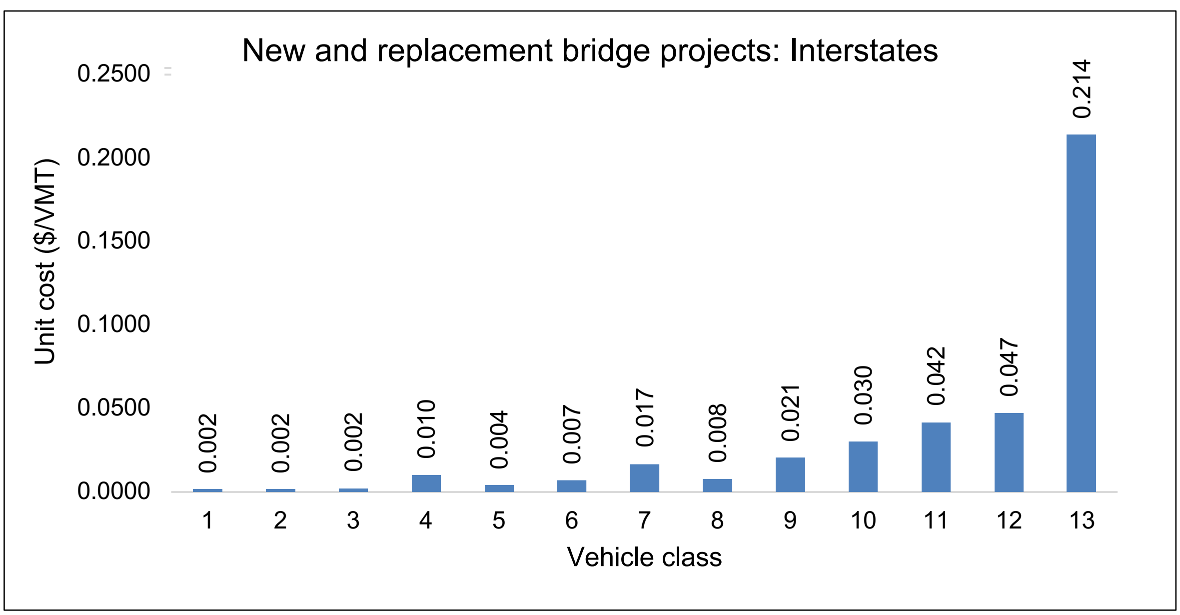


Figure 4.33: Unit cost ($/VMT) for new and replacement bridge projects on interstates, 2014-2017.

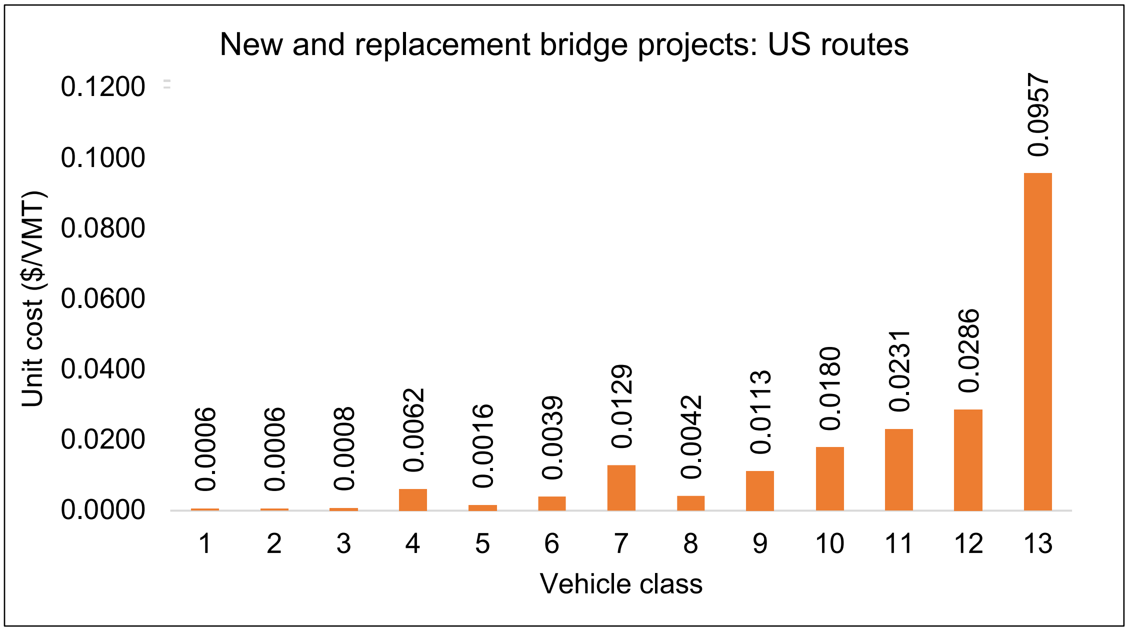


Figure 4.34: Unit cost ($/VMT) for new and replacement bridge projects on US routes, 2014-2017.

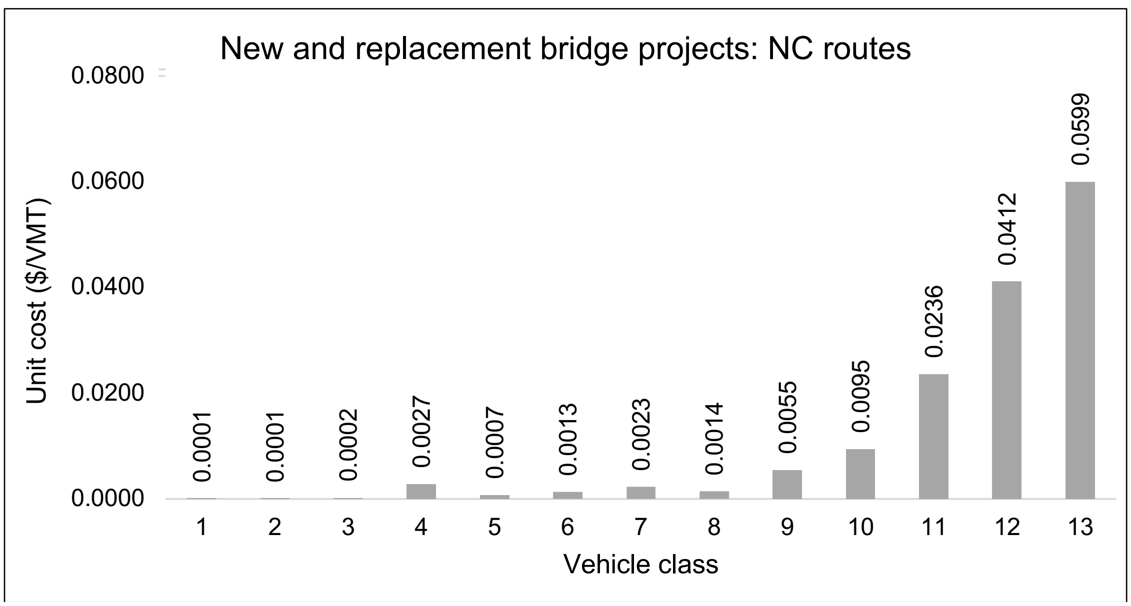


Figure 4.35: Unit cost ($/VMT) for new and replacement bridge projects on NC routes, 2014-2017.

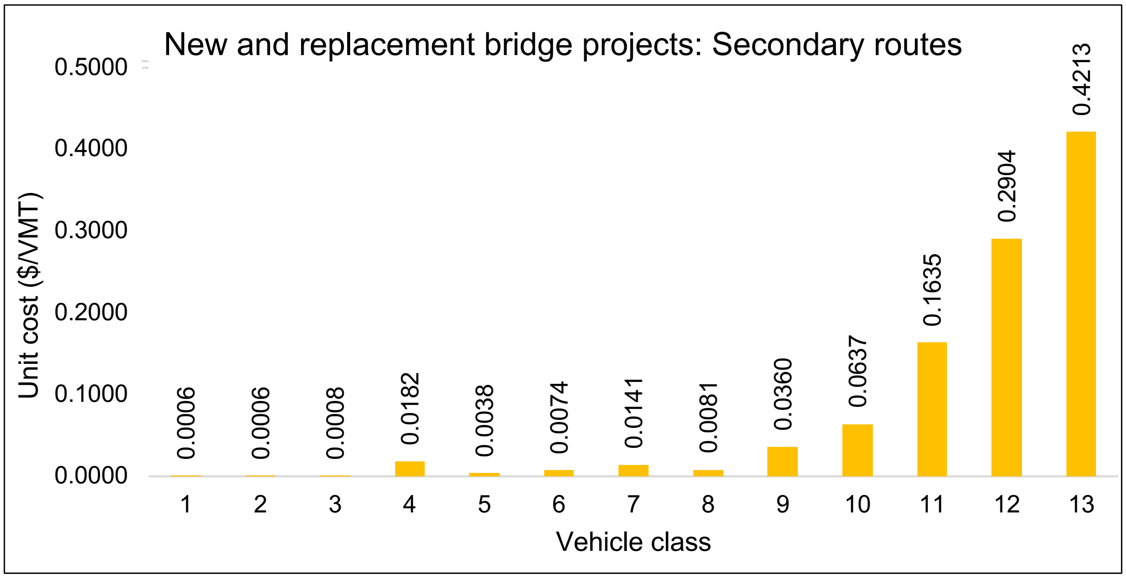


Figure 4.36: Unit cost ($/VMT) for new and replacement bridge projects on secondary routes, 2014-2017.

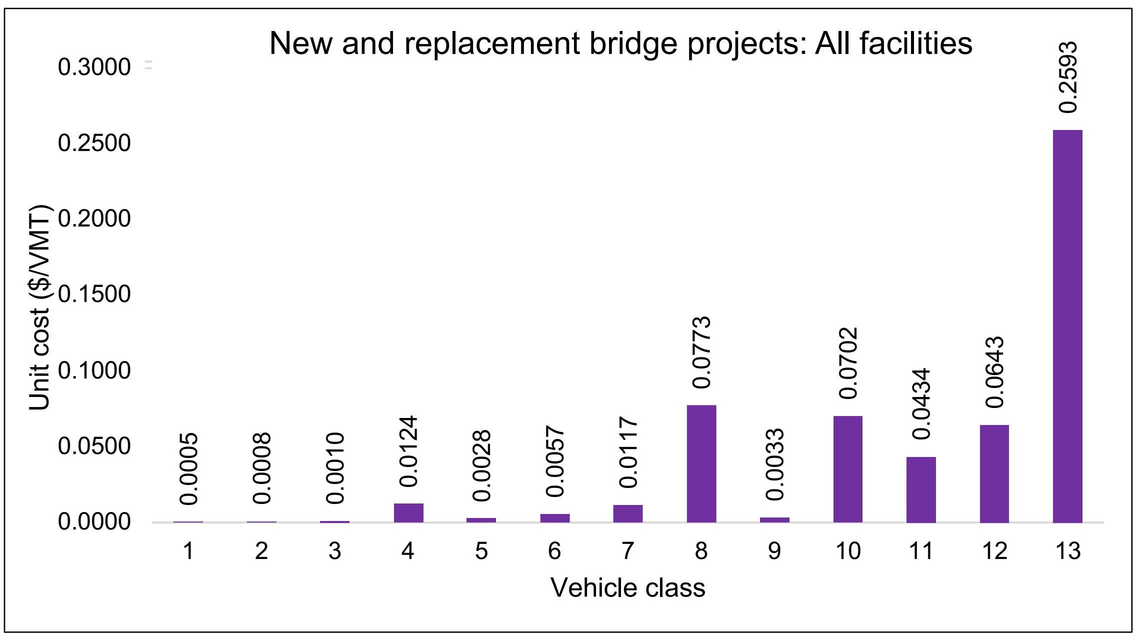


Figure 4.37: Unit cost ($/VMT) for new and replacement bridge projects on all facilities, 2014-2017.

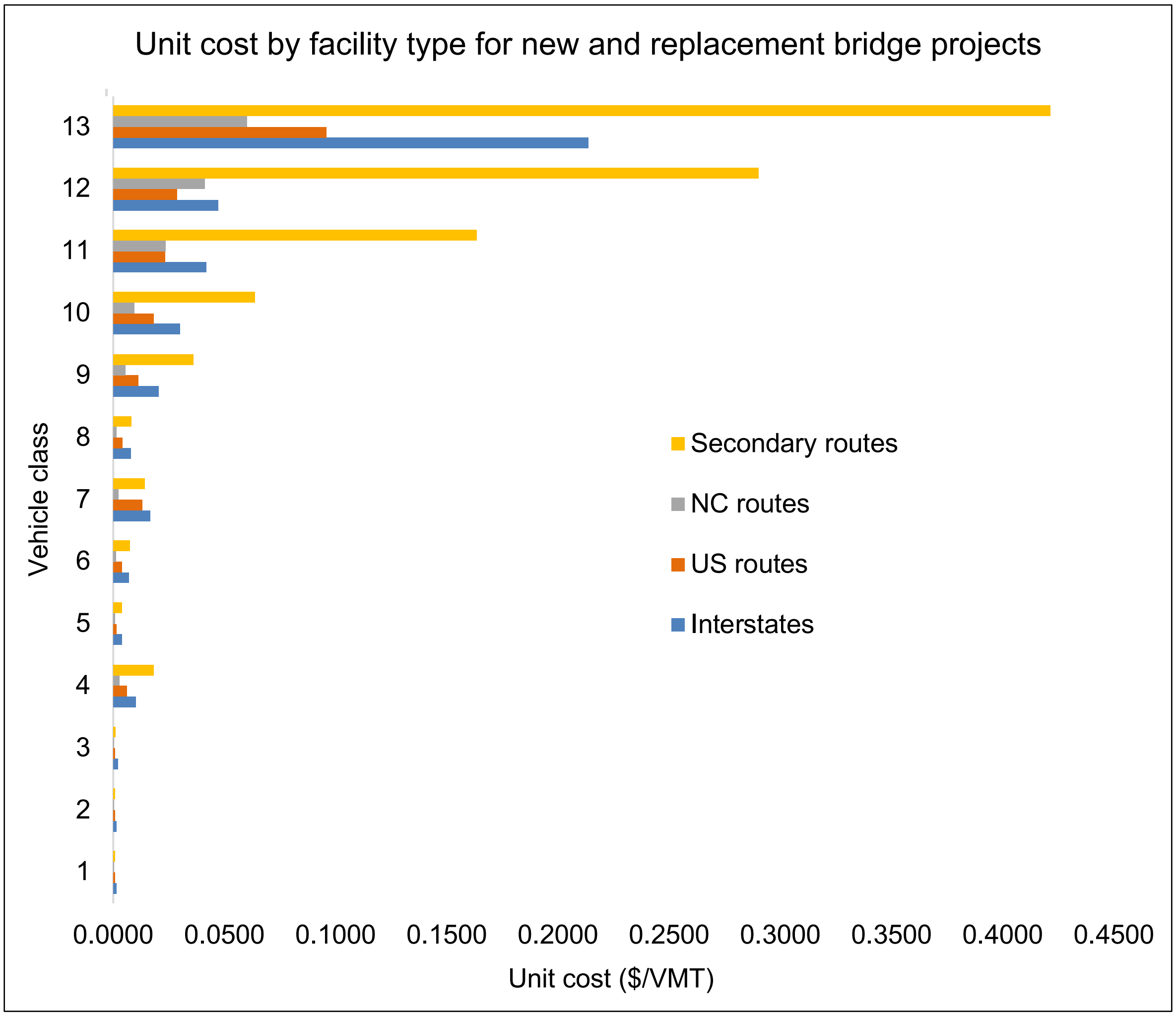


Figure 4.38: Unit cost ($/VMT) by facility type for new and replacement bridge projects, 2014-2017.

Table 4.26 and Figure 4.33 to Figure 4.38 show that the highest unit cost is associated with vehicle class 13 for all types of highway facilities. The combined unit cost for all facilities (Figure 4.37) shows that among the single-unit trucks (FHWA vehicle class 4 to 7), class 8, and among the multi-unit trucks (FHWA vehicle class 8 to 13), class 13, have the highest unit cost.

It should be noted that the first vehicle class in the 20-vehicle class system used in FHWA HCAS tool consists of both auto and motorcycle (Table 3.8). Therefore, during load related cost allocation, the VMTs of motorcycle and autos were combined under the first class, and later the allocated costs were redistributed as per their corresponding VMT shares. This explains the similar unit travel costs for motorcycle (class 1) and autos (class 2) in FHWA 13 vehicle class system (Figure 4.33 to Figure 4.36).

4.3.2 Bridge Rehabilitation

4.3.2.1 Bridge Rehabilitation Projects

A total of 644 bridge related rehabilitation projects were conducted from 2014 to 2017. The project costs were distributed among the four highway classes based on the location descriptions. Sixty-seven of these projects' descriptions did not include any information about the facility location of the project. These projects were classified under "Mixed" facility.

Table 4.27: Bridge rehabilitation costs ($Millions) by year and facility type.

Year	Interstate	US	NC	SR	Mixed	Total by Year
2014	0.19	57.43	29.50	106.62	23.29	217.01
2015	2.07	25.23	36.23	120.35	14.40	198.27
2016	0.77	66.87	7.53	64.57	9.20	148.95
2017	6.42	36.92	22.74	114.74	3.38	184.20
Total by Facility	2.36	46.61	24.00	101.57	12.57	**748.43**
Average by Facility	2.7	44.3	24.2	102.2	13.8	

Table 4.27 shows that the total cost in bridge rehabilitation projects is nearly $749 million from 2014 to 2017. Figure 4.39 shows the bridge rehabilitation cost distribution on the four highway facilities carried out each year.

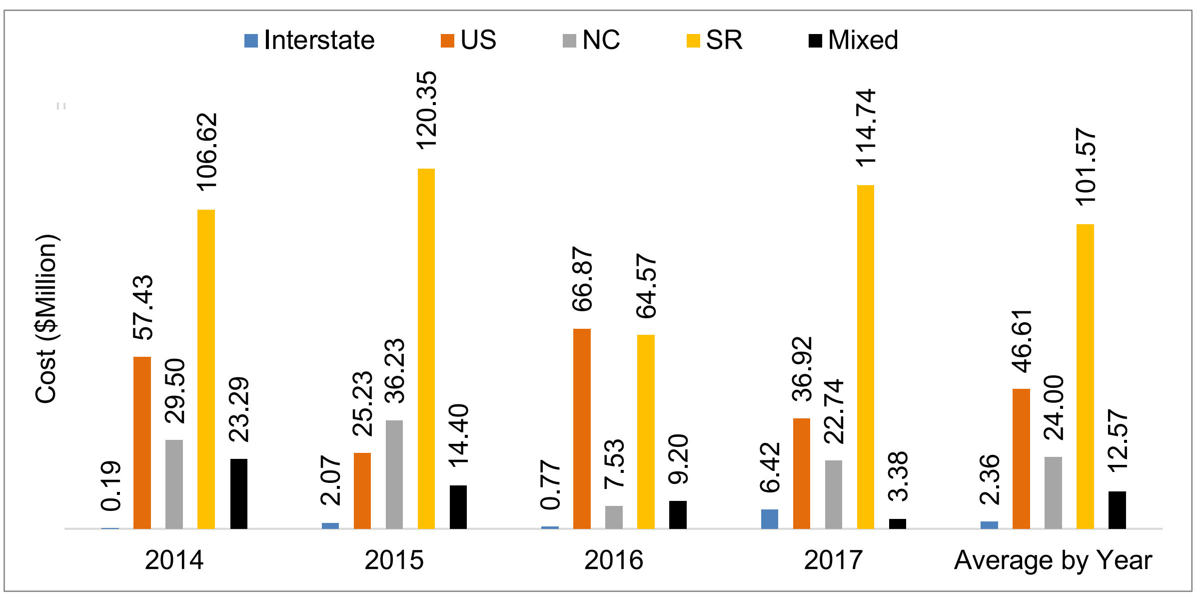


Figure 4.39: Bridge rehabilitation costs ($Million) by year and facility type.

Table 4.27 and Figure 4.39 show that the largest and the smallest shares of the bridge rehabilitation projects are carried out on secondary routes and interstate routes, respectively. A total 462 projects out of the 644 bridge rehabilitation projects are carried out on various secondary routes, costing an average $101.57 million per year.

4.3.2.2 Methodology

This study used the FHWA HCAS method to allocate the bridge rehabilitation costs. According to 1997 FHWA HCAS, bridge rehabilitation costs are divided into major and minor rehabilitation work. The minor rehabilitation projects were assumed to be non-load related costs and thereby were allocated based on VMT. The load related bridge rehabilitation projects include bridge replacement and repair work. These were allocated using the FHWA HCAS tool.

4.3.2.3 Bridge Rehabilitation Cost Allocation Results

The non-load related costs of the bridge rehabilitation projects on four types of highway facilities and mixed facilities were distributed according to the VMTs and are reported in Table 4.28.

Table 4.28: Cost responsibility ($) by facility type for non-load related bridge rehabilitation works, 2014-2017.

Vehicle Class		Interstate	US	NC	SR	Mixed	All Facility	All Facility (%)
MC	**1**	546	24,558	3,910	39,762	9,079	77,856	0.64%
Cars	**2**	97,115	3,558,370	521,146	3,641,404	1,114,359	8,932,393	73.64%
2A4T	**3**	20,187	852,445	128,893	984,701	278,794	2,265,020	18.67%
Bus	**4**	664	26,594	3,807	47,273	9,860	88,198	0.73%
2ASU	**5**	2,477	111,927	16,775	144,389	37,700	313,267	2.58%
3ASU	**6**	762	28,631	4,092	41,365	9,853	84,704	0.70%
4ASU	**7**	37	3,571	469	3,211	1,045	8,333	0.07%
4AST	**8**	825	33,716	4,596	32,207	10,131	81,475	0.67%
5AST	**9**	9,208	118,120	13,099	80,933	30,803	252,164	2.08%
6AST	**10**	120	7,027	917	7,935	2,179	18,178	0.15%
5AMT	**11**	183	2,312	134	409	422	3,460	0.03%
6AMT	**12**	84	898	60	265	178	1,486	0.01%
7AMT	**13**	20	1,468	181	1,913	468	4,048	0.03%
Total Cost		132,229	132,229	4,769,637	698,079	5,025,767	12,130,582	100%

For the load related costs, this study used the FHWA HCAS tool. The FHWA HCAS tool allocates load related costs among 20 types of vehicles. It uses a distribution that combines motorcycle and automobiles in one group and subdivides class 8, 9, 10 and 13 vehicles into three more classes each. This study used those distributions to redistribute the VMTs from 13 vehicle classes to 20 vehicle classes (Table 3.8 and Table 3.9).

Like the pavement rehabilitation expenditure, project details did not list the type of rehabilitation work (flexible or rigid). Therefore, this study used a ratio of 90:10 for flexible and rigid bridge related rehabilitation expenditures, based on expert opinion.

Table 4.29 presents the load related bridge rehabilitation costs allocated to the 13 FHWA vehicle classes. Similar to the pavement rehabilitation costs, we used NCDOT's WIM distribution to allocate the costs on interstate and US routes, and FHWA's default WIM distribution to allocate the costs on other highway routes. Table 4.30 presents the total cost responsibilities (load and non-load related) of different vehicle or highway user groups on different highway facilities.

Table 4.29: Cost responsibility ($Millions) by facility type for load related bridge rehabilitation works, 2014-2017.

Vehicle Class		Interstate	US	NC	SR	Mixed	All Facility	All Facility (%)
MC	**1**	0.02	0.61	0.33	1.68	0.19	2.83	0.38%
Cars	**2**	4.05	88.42	43.32	153.82	23.06	312.67	42.47%
2A4T	**3**	1.11	29.17	15.03	53.85	7.36	106.52	14.47%
Bus	**4**	0.12	4.11	3.06	27.56	1.97	36.82	5.00%
2ASU	**5**	0.23	7.50	5.87	25.34	2.45	41.39	5.62%
3ASU	**6**	0.11	3.51	2.14	12.57	0.94	19.27	2.62%
4ASU	**7**	0.01	0.90	0.35	1.49	0.18	2.93	0.40%
4AST	**8**	0.14	4.75	2.74	10.11	1.10	18.84	2.56%
5AST	**9**	3.26	35.84	18.02	78.35	9.46	144.93	19.68%
6AST	**10**	0.05	2.92	1.82	13.74	0.88	19.42	2.64%
5AMT	**11**	0.11	1.12	0.53	1.67	0.34	3.76	0.51%
6AMT	**12**	0.06	0.55	0.40	1.97	0.20	3.18	0.43%
7AMT	**13**	0.05	2.28	1.70	19.10	0.62	23.75	3.23%
Total Costs		9.32	181.68	95.29	401.24	48.76	736.30	100%

Table 4.30: Cost responsibility ($Millions) by facility type for bridge rehabilitation projects, 2014-2017.

Vehicle Class		Interstate	US	NC	SR	Mixed	All facility	All Facility (%)
MC	1	0.02	0.63	0.33	1.72	0.20	2.90	0.39%
Cars	2	4.15	91.98	43.84	157.46	24.18	321.60	42.97%
2A4T	3	1.13	30.03	15.16	54.83	7.64	108.78	14.54%
Bus	4	0.12	4.14	3.06	27.61	1.98	36.91	4.93%
2ASU	5	0.24	7.61	5.88	25.48	2.49	41.71	5.57%
3ASU	6	0.12	3.54	2.14	12.61	0.95	19.36	2.59%
4ASU	7	0.01	0.90	0.36	1.49	0.18	2.94	0.39%
4AST	8	0.14	4.78	2.75	10.14	1.11	18.92	2.53%
5AST	9	3.27	35.96	18.03	78.43	9.49	145.18	19.40%
6AST	10	0.05	2.92	1.82	13.75	0.88	19.44	2.59%
5AMT	11	0.11	1.12	0.53	1.67	0.34	3.76	0.51%
6AMT	12	0.06	0.56	0.40	1.97	0.20	3.18	0.43%
7AMT	13	0.05	2.28	1.70	19.10	0.62	23.75	3.17%
Total Costs		9.45	186.45	95.99	406.27	50.27	748.43	100%

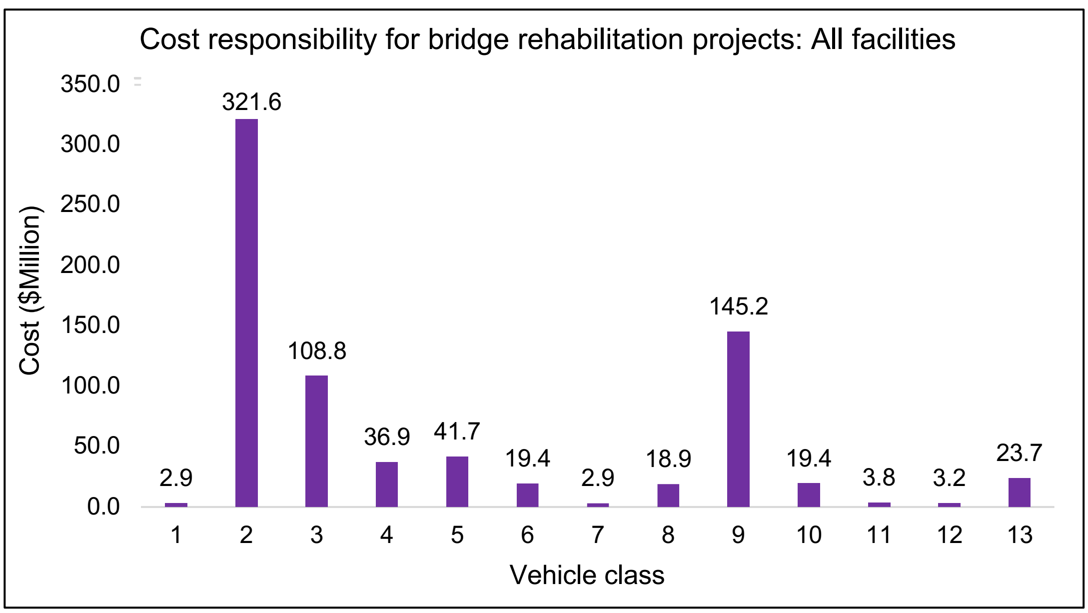


Figure 4.40: Cost responsibility ($Millions) for bridge rehabilitation projects on all facilities, 2014-2017.

As seen before, it is difficult to understand the cost shares for each vehicle type, as some vehicle classes have more VMTs than others. Table 4.31 presents the cost responsibilities in $/VMT units from all load and non-load related pavement rehabilitation project costs. Figure 4.41 to Figure 4.45 show the unit cost in $/VMT for interstate, US, NC, secondary and mixed routes, respectively, and Figure 4.46 shows the unit cost for all the facility types. Figure 4.47 compares the unit costs of the 13 vehicle classes on each of the highway facility type for bridge rehabilitation projects.

Table 4.31: Unit cost ($/VMT) by facility type for bridge rehabilitation projects, 2014-2017.

Vehicle Class		Interstate	US	NC	SR	Mixed	All Facility
MC	**1**	0.0001	0.0013	0.0009	0.0014	0.0009	0.0010
Cars	**2**	0.0001	0.0013	0.0009	0.0014	0.0009	0.0010
2A4T	**3**	0.0001	0.0018	0.0012	0.0018	0.0011	0.0013
Bus	**4**	0.0002	0.0078	0.0085	0.0188	0.0081	0.0119
2ASU	**5**	0.0001	0.0034	0.0037	0.0057	0.0027	0.0037
3ASU	**6**	0.0002	0.0062	0.0055	0.0098	0.0039	0.0063
4ASU	**7**	0.0004	0.0127	0.0080	0.0150	0.0069	0.0109
4AST	**8**	0.0002	0.0071	0.0063	0.0101	0.0044	0.0063
5AST	**9**	0.0005	0.0153	0.0146	0.0312	0.0124	0.0104
6AST	**10**	0.0006	0.0209	0.0211	0.0557	0.0163	0.0314
5AMT	**11**	0.0008	0.0244	0.0415	0.1313	0.0321	0.0170
6AMT	**12**	0.0009	0.0310	0.0693	0.2388	0.0453	0.0317
7AMT	**13**	0.0031	0.0781	0.0999	0.3211	0.0531	0.1794

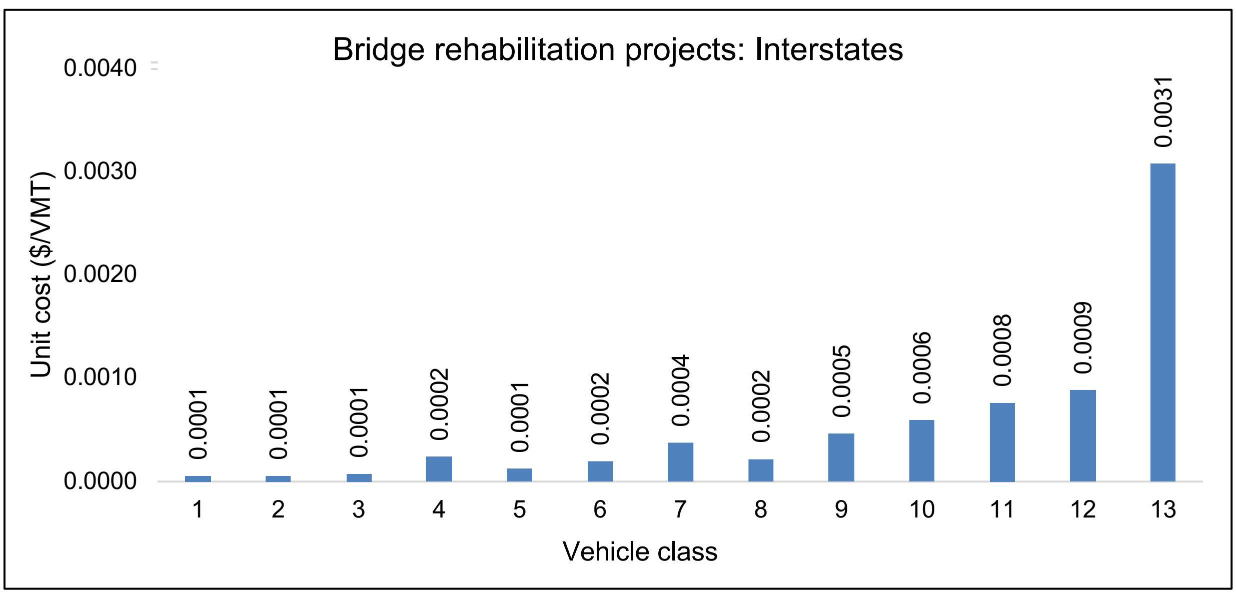


Figure 4.41: Unit cost ($/VMT) for bridge rehabilitation projects on interstates, 2014-2017.

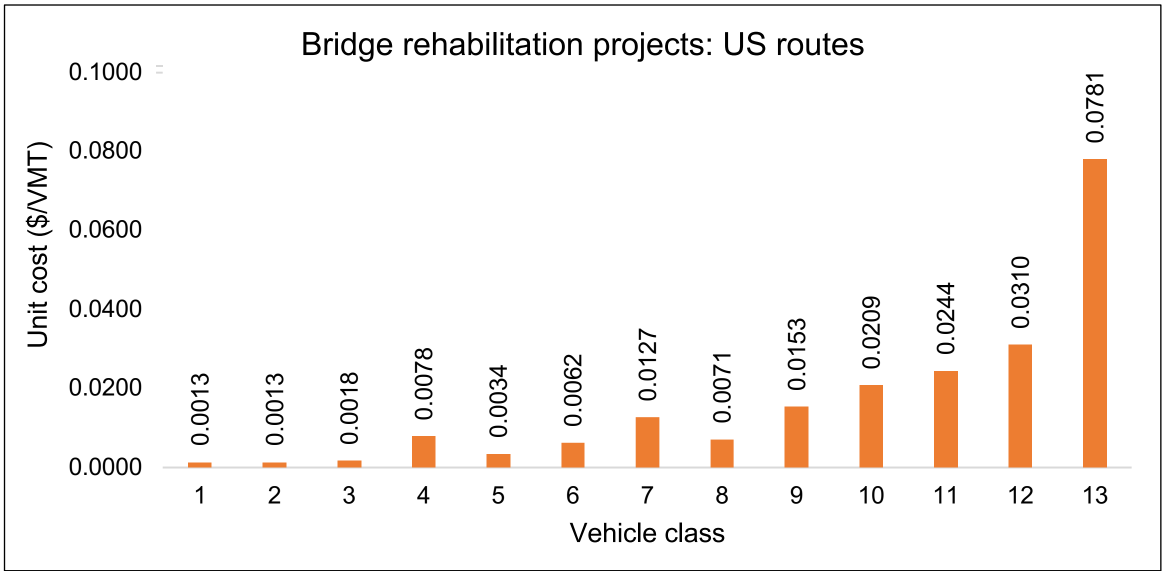


Figure 4.42: Unit cost ($/VMT) for bridge rehabilitation projects on US routes, 2014-2017.

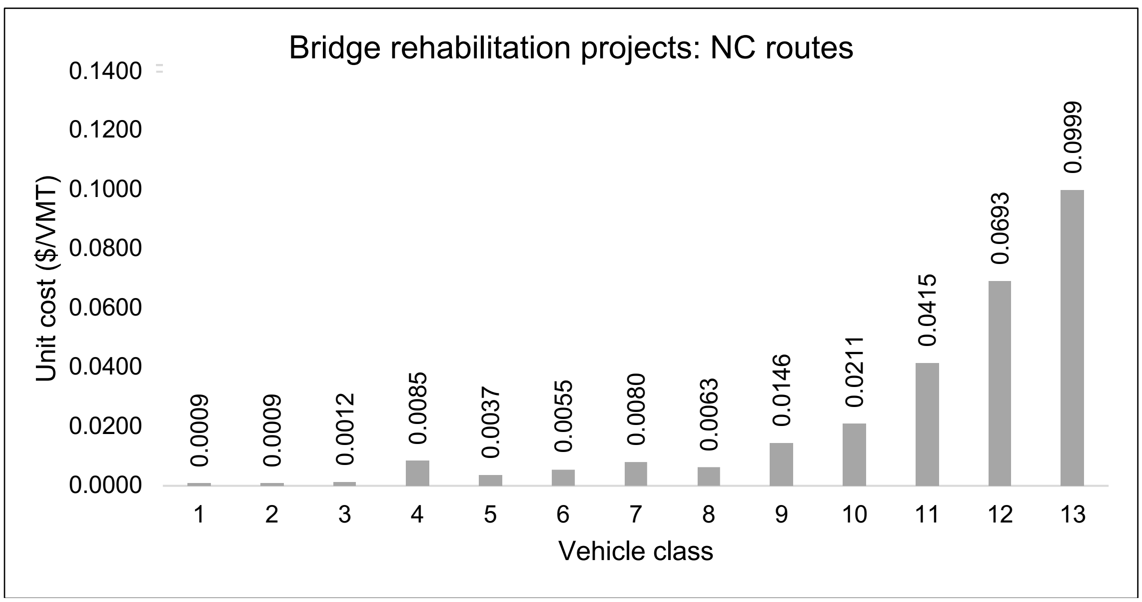


Figure 4.43: Unit cost ($/VMT) for bridge rehabilitation projects on NC routes, 2014-2017.

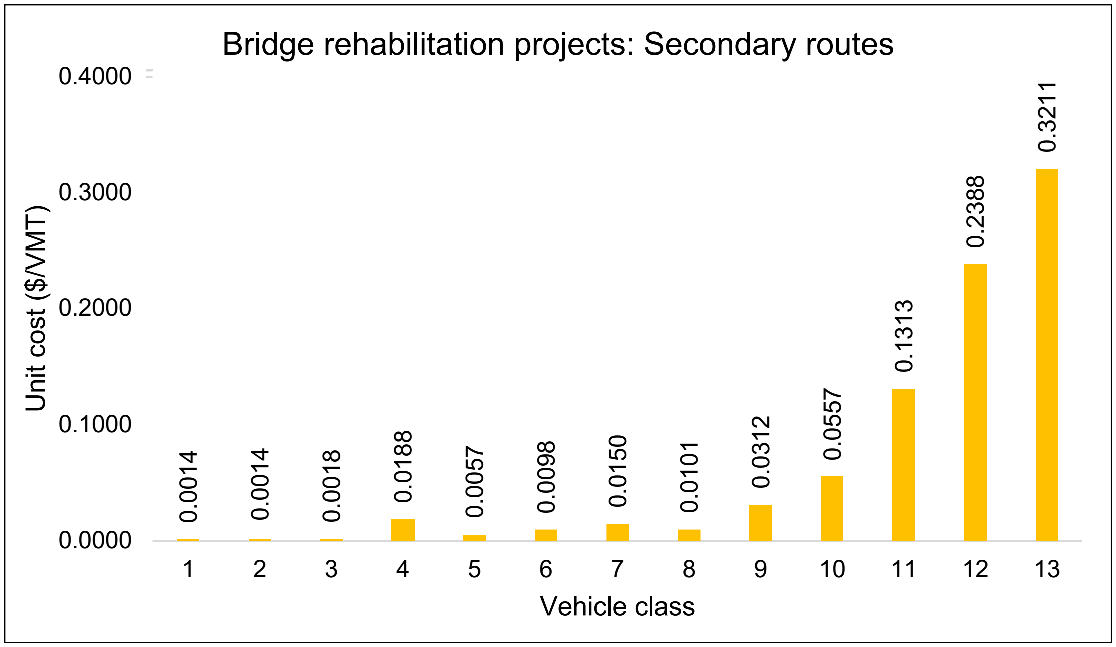


Figure 4.44: Unit cost ($/VMT) for bridge rehabilitation projects on secondary routes, 2014-2017.

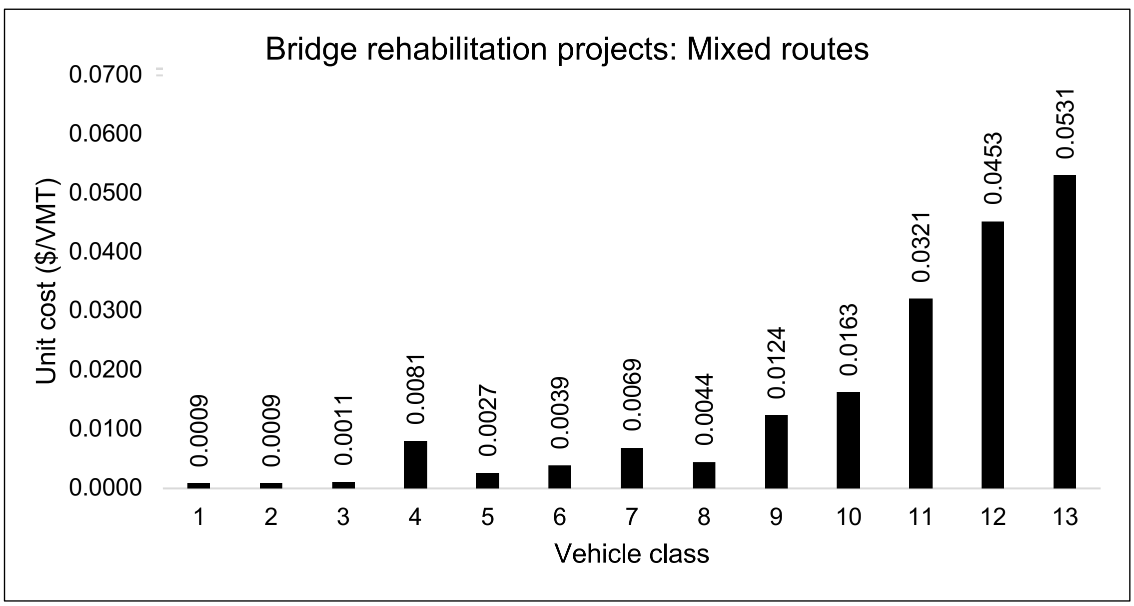


Figure 4.45: Unit cost ($/VMT) for bridge rehabilitation projects on mixed routes, 2014-2017.

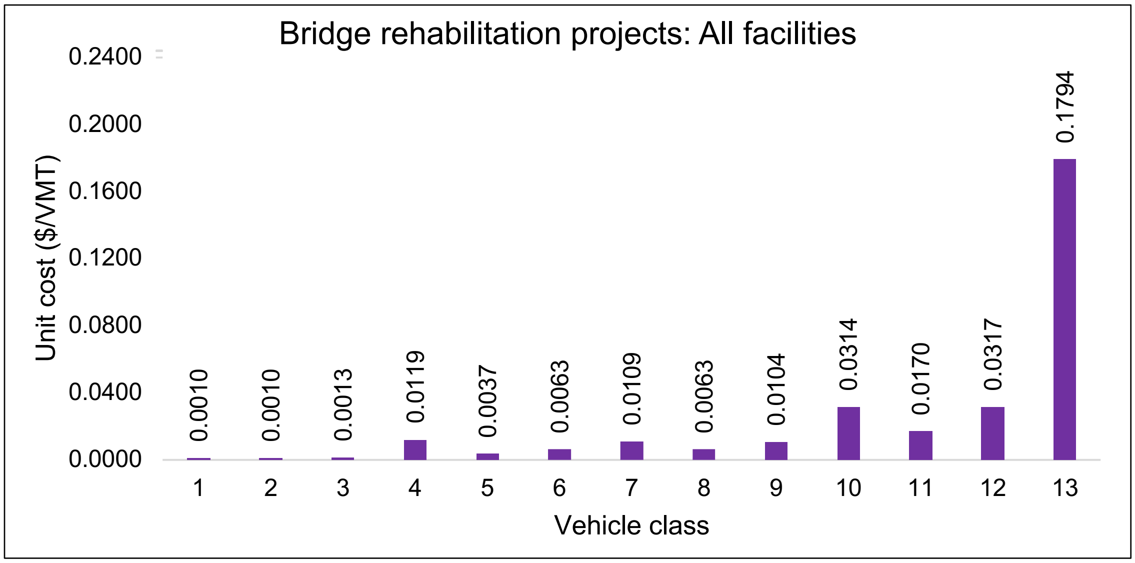


Figure 4.46: Unit cost ($/VMT) for bridge rehabilitation projects on all highway facilities, 2014-2017.

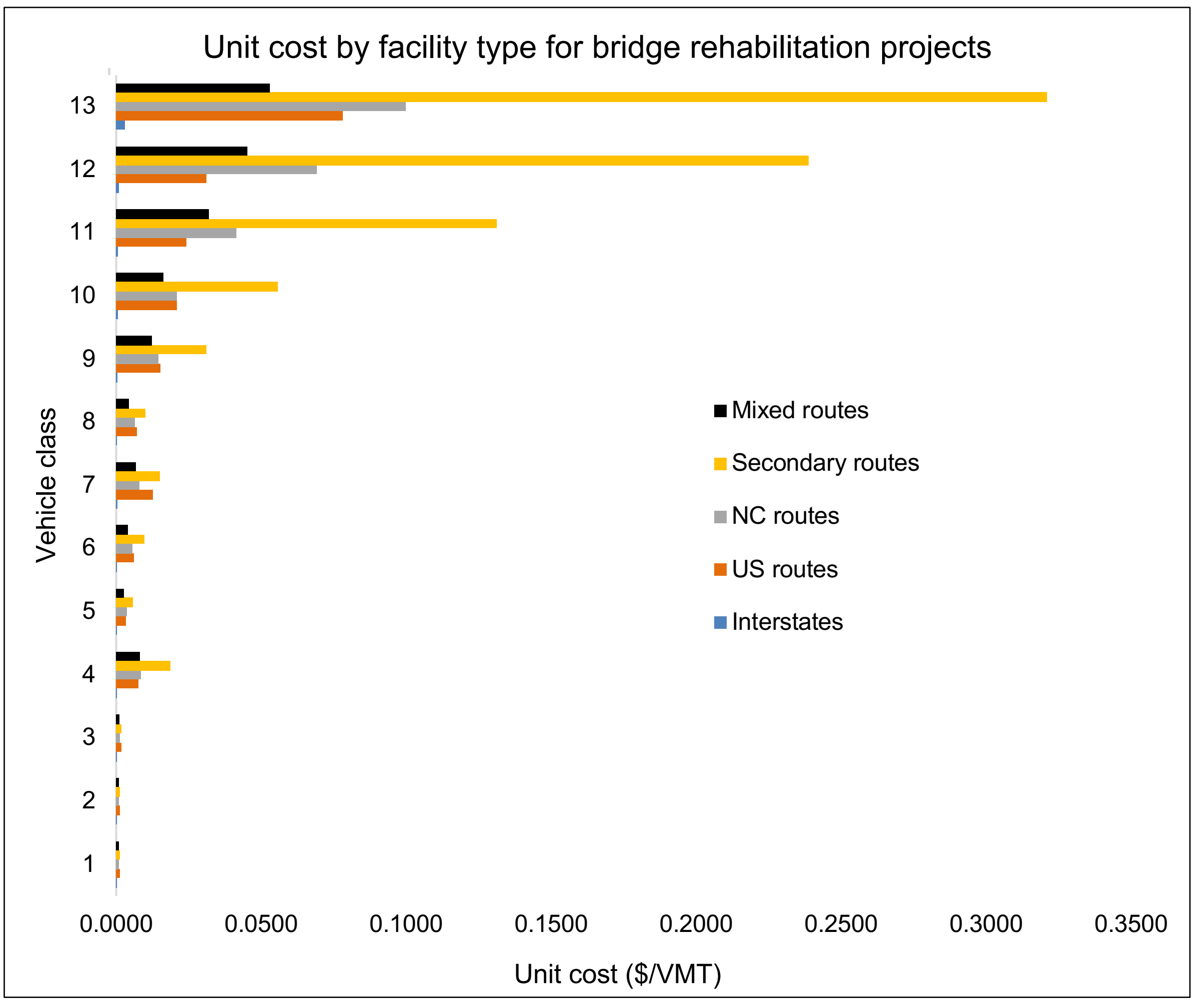


Figure 4.47: Unit cost ($/VMT) for bridge rehabilitation projects by facility type, 2014-2017.

Figure 4.40 shows that the passenger cars have the highest share of total cost responsibility for bridge rehabilitation projects. However, from Figure 4.47 and Figure 4.41 to Figure 4.45, we see that the highest unit cost is associated with vehicle class 13 for all types of highway facilities. The combined unit cost for all facilities (Figure 4.46) shows that the among the single-unit trucks (vehicle classes 4 to 7), vehicle class 4 has the highest unit cost, and among the multi-unit trucks (vehicle classes 8 to 13), vehicle class 13 has higher unit costs than all of the vehicle classes.

It should be noted that the first vehicle class in the 20-vehicle class system used in HCAS tool consists of both auto and motorcycle (Table 3.8). Therefore, during load related cost allocation, the VMTs of motorcycles and autos were combined under the first class, and later the allocated costs were redistributed as per their corresponding VMT shares. This explains the similar unit travel costs for motorcycle (class 1) and autos (class 2) in FHWA 13 vehicle class system (Figure 4.41 to Figure 4.47).

4.3.3 In-House Maintenance of Bridges

The bridge related in-house maintenance costs are allocated in the same fashion as the pavement in-house maintenance costs (section 4.2.3). Table 4.32 presents the total bridge related in-house maintenance expenditures from 2014 to 2017.

Table 4.32: Total costs ($Millions) by year and facility type for bridge related in-house maintenance projects.

Year	Interstate	US	NC	Secondary	Total by Year
2014	1.03	4.82	7.25	27.56	40.67
2015	0.93	4.30	6.50	27.09	38.82
2016	1.18	4.05	6.08	26.46	37.77
2017	1.13	4.02	6.04	38.14	49.33
Total by Facility	4.27	17.20	25.87	119.25	166.58
Average annual by facility type	1.07	4.30	6.47	29.81	

As described in section 4.2.3, the bridge related in-house maintenance costs are also divided into load and non-load related portions. We considered 50% of the total costs for subtype “Bridge Program” and “System Preservation” as load-related expenditure and distributed these costs using the FHWA HCAS tool following the same procedure as the bridge rehabilitation project cost allocation. Bridge related in-house maintenance costs with project subtype “Standing” are considered non-load related in-house maintenance projects. The non-load related portions of the bridge in-house maintenance costs are distributed as per VMTs. Table 4.33 shows the load and non-load related costs on the four highway facilities for in-house maintenance works from 2014 to 2017. Like the pavement related in-house maintenance projects, the average urban-rural shares from bridge rehabilitation projects are used to split the in-house maintenance costs into urban and rural area types. Costs from bridge related in-house maintenance projects were not split into flexible and rigid pavement, as the FHWA HCAS tool does not require these costs to be separated according to structure type.

Table 4.33: Load and non-load related cost shares ($) by facility type for bridge related in-house maintenance projects, 2014-2017.

	Interstate	US	NC	Secondary
Load-related cost	56,620	246,208	374,961	1,320,843
Non-load related costs	4,210,676	16,952,639	25,496,287	117,924,432
Total cost by facility	4,267,296	17,198,847	25,871,248	119,245,275

Table 4.34 to Table 4.36 present the non-load, load related, and total cost shares of the 13 FHWA vehicle classes for pavement in-house maintenance expenditures from 2014 to 2017. Table 4.37 presents the unit cost shares in $/VMT.

Table 4.34: Cost responsibility ($) by facility type and vehicle class for non-load related bridge in-house maintenance works, 2014-2017.

Vehicle Class		Interstate	US	NC	SR	All Facility	All Facility (%)
MC	**1**	17,398	87,286	142,814	932,978	1,180,476	0.72%
Cars	**2**	3,092,506	12,647,452	19,034,054	85,441,784	120,215,796	73.04%
2A4T	**3**	642,829	3,029,829	4,707,637	23,104,994	31,485,290	19.13%
Bus	**4**	21,159	94,521	139,044	1,109,210	1,363,934	0.83%
2ASU	**5**	78,863	397,820	612,682	3,387,928	4,477,293	2.72%
3ASU	**6**	24,275	101,764	149,447	970,598	1,246,084	0.76%
4ASU	**7**	1,190	12,693	17,141	75,336	106,360	0.06%
4AST	**8**	26,276	119,835	167,870	755,705	1,069,686	0.65%
5AST	**9**	293,232	419,833	478,414	1,899,011	3,090,491	1.88%
6AST	**10**	3,822	24,978	33,479	186,187	248,466	0.15%
5AMT	**11**	5,829	8,218	4,903	9,593	28,544	0.02%
6AMT	**12**	2,671	3,193	2,206	6,220	14,291	0.01%
7AMT	**13**	624	5,216	6,594	44,886	57,321	0.03%
Total Cost		4,210,676	16,952,639	25,496,287	44,886	117,924,432	100%

Table 4.35: Cost responsibility ($) by facility type for load related bridge in-house maintenance works, 2014-2017.

Vehicle Class		Interstate	US	NC	SR	All Facility	All Facility (%)
MC	**1**	143	846	1,413	6,937	9,339	0.47%
Cars	**2**	25,496	122,647	188,261	635,250	971,654	48.62%
2A4T	**3**	6,939	39,138	60,212	223,148	329,437	16.48%
Bus	**4**	709	5,411	10,342	59,847	76,309	3.82%
2ASU	**5**	1,434	9,962	22,994	91,362	125,752	6.29%
3ASU	**6**	695	4,708	8,234	38,225	51,862	2.59%
4ASU	**7**	62	1,206	1,273	4,019	6,559	0.33%
4AST	**8**	831	6,232	10,324	33,583	50,971	2.55%
5AST	**9**	18,948	47,270	60,925	183,819	310,962	15.56%
6AST	**10**	300	3,761	5,132	21,604	30,796	1.54%
5AMT	**11**	559	1,455	1,309	1,961	5,283	0.26%
6AMT	**12**	301	731	933	2,041	4,005	0.20%
7AMT	**13**	202	2,839	3,611	19,048	25,700	1.29%
Total Cost		56,620	246,208	374,961	1,320,843	1,998,632	100%

Table 4.36: Cost responsibility ($) by facility type for bridge in-house maintenance projects, 2014-2017.

Vehicle Class		Interstate	US	NC	SR	All Facility	All Facility (%)
MC	**1**	17,542	88,133	144,226	939,914	1,189,815	0.71%
Cars	**2**	3,118,002	12,770,099	19,222,315	86,077,034	121,187,450	72.75%
2A4T	**3**	649,769	3,068,967	4,767,850	23,328,142	31,814,727	19.10%
Bus	**4**	21,868	99,933	149,386	1,169,056	1,440,243	0.86%
2ASU	**5**	80,297	407,782	635,676	3,479,290	4,603,045	2.76%
3ASU	**6**	24,970	106,472	157,681	1,008,824	1,297,947	0.78%
4ASU	**7**	1,252	13,899	18,414	79,355	112,920	0.07%
4AST	**8**	27,107	126,068	178,194	789,288	1,120,657	0.67%
5AST	**9**	312,181	467,103	539,339	2,082,830	3,401,453	2.04%
6AST	**10**	4,122	28,738	38,610	207,791	279,262	0.17%
5AMT	**11**	6,388	9,674	6,212	11,554	33,828	0.02%
6AMT	**12**	2,972	3,924	3,139	8,261	18,296	0.01%
7AMT	**13**	827	8,055	10,206	63,934	83,022	0.05%
Total Cost		4,267,296	17,198,847	25,871,248	119,245,275	166,582,665	**100%**

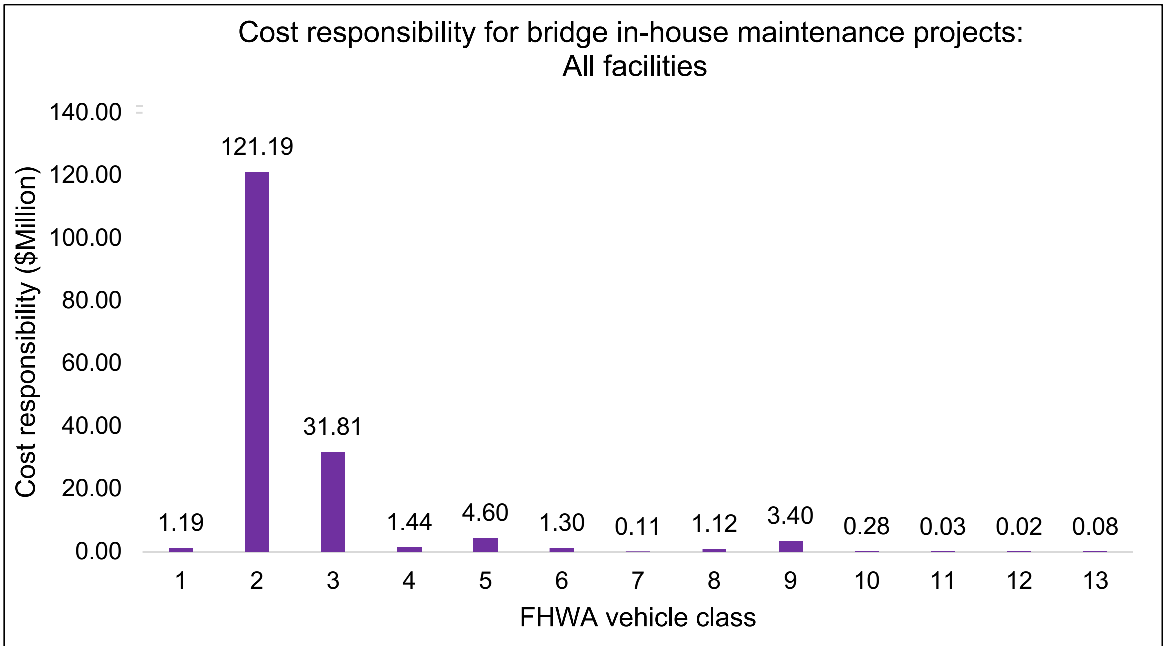


Figure 4.48: Cost responsibility ($Million) by vehicle class for bridge in-house maintenance projects on all facilities, 2014-2017.

Table 4.37: Unit cost ($/VMT) by facility type for bridge in-house maintenance projects, 2014-2017.

Vehicle Class		Interstate	US	NC	SR	All Facility
MC	**1**	0.00004	0.00016	0.00033	0.00071	0.00043
Cars	**2**	0.00004	0.00016	0.00033	0.00071	0.00036
2A4T	**3**	0.00004	0.00016	0.00033	0.00072	0.00039
Bus	**4**	0.00004	0.00016	0.00035	0.00075	0.00046
2ASU	**5**	0.00004	0.00016	0.00034	0.00073	0.00041
3ASU	**6**	0.00004	0.00016	0.00034	0.00074	0.00042
4ASU	**7**	0.00004	0.00017	0.00035	0.00075	0.00042
4AST	**8**	0.00004	0.00016	0.00035	0.00074	0.00038
5AST	**9**	0.00004	0.00017	0.00037	0.00078	0.00024
6AST	**10**	0.00005	0.00018	0.00038	0.00079	0.00045
5AMT	**11**	0.00005	0.00018	0.00041	0.00085	0.00015
6AMT	**12**	0.00005	0.00019	0.00046	0.00094	0.00018
7AMT	**13**	0.00006	0.00024	0.00050	0.00101	0.00063

Figure 4.49 through Figure 4.52 show the unit cost in $/VMT for interstate, US, NC, and secondary routes, respectively, and Figure 4.53 shows the unit cost for all highway facilities combined. Figure 4.54 compares the unit costs of the 13 vehicle classes on each highway facility.

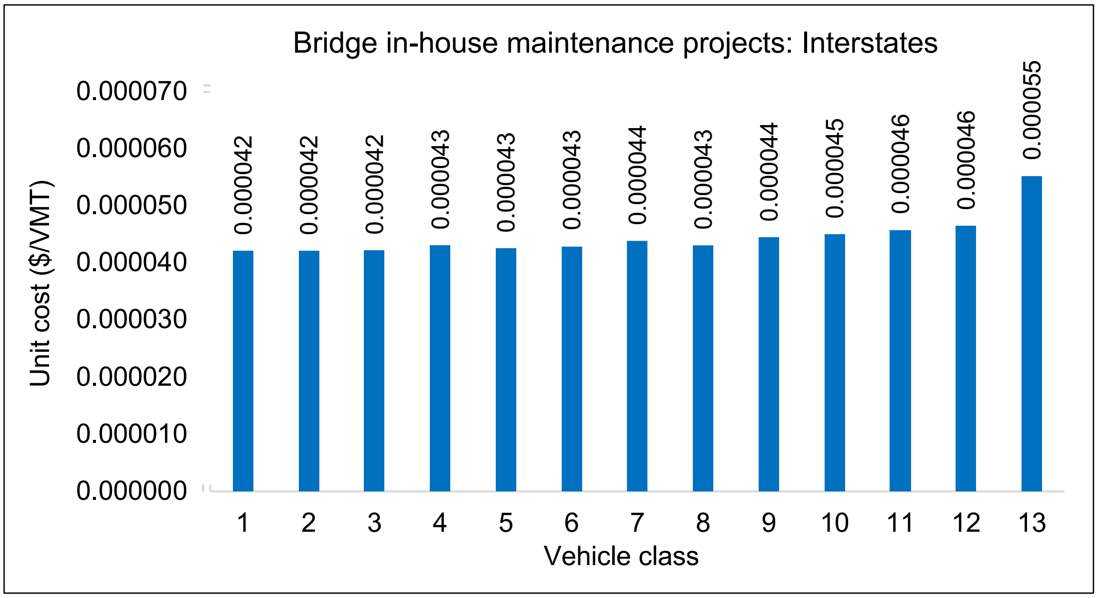


Figure 4.49: Unit cost ($/VMT) for bridge in-house maintenance projects on interstates, 2014-2017.

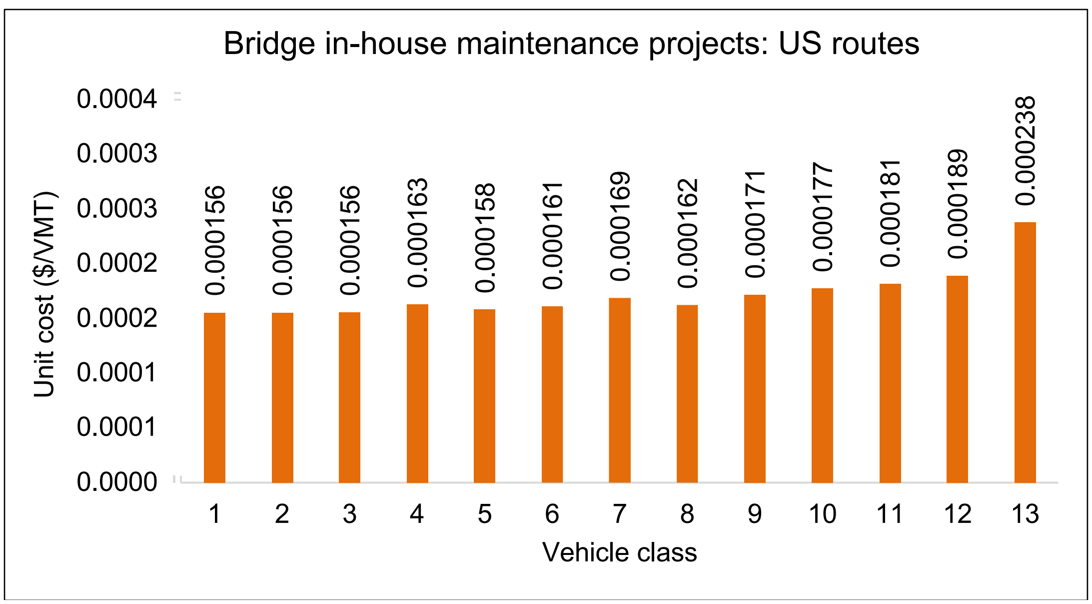


Figure 4.50: Unit cost ($/VMT) for bridge in-house maintenance projects on US routes, 2014-2017.

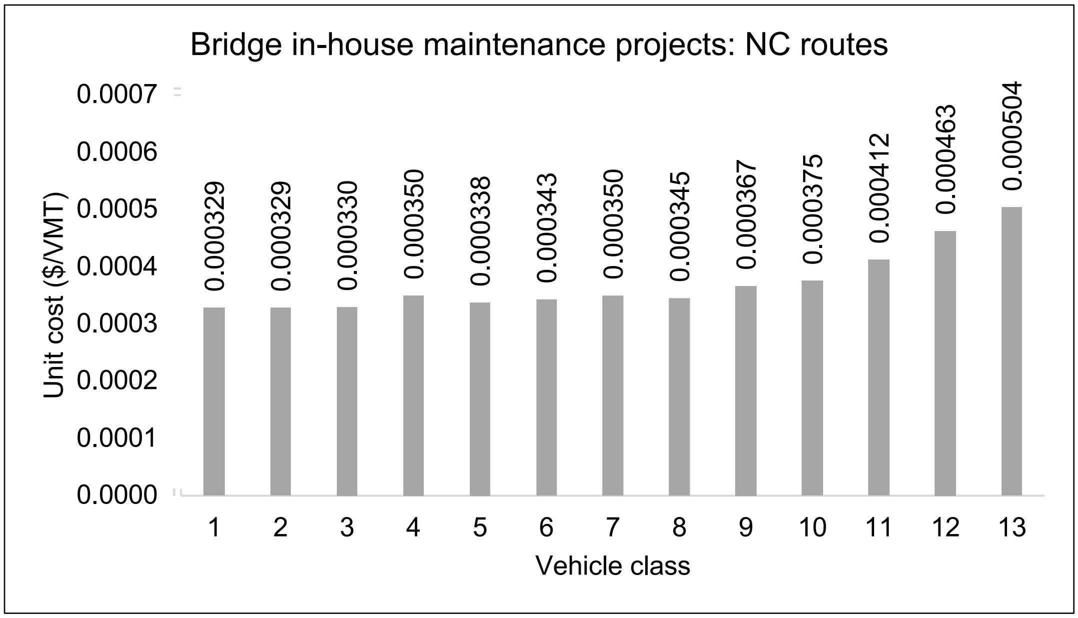


Figure 4.51: Unit cost ($/VMT) for bridge in-house maintenance projects on NC routes, 2014-2017.

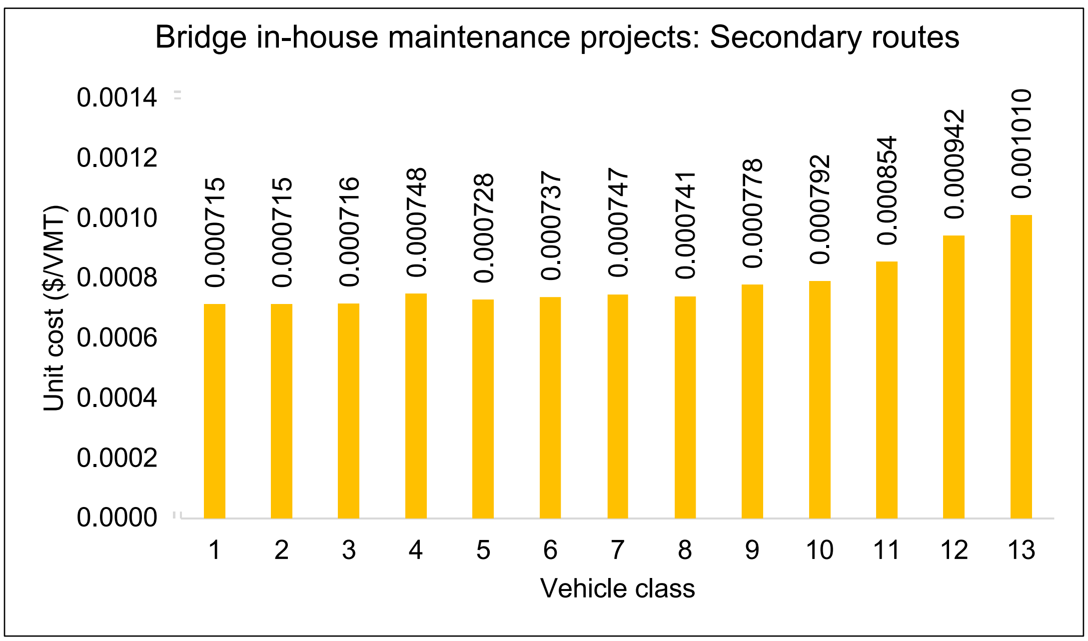


Figure 4.52: Unit cost ($/VMT) for bridge in-house maintenance projects on secondary routes, 2014-2017.

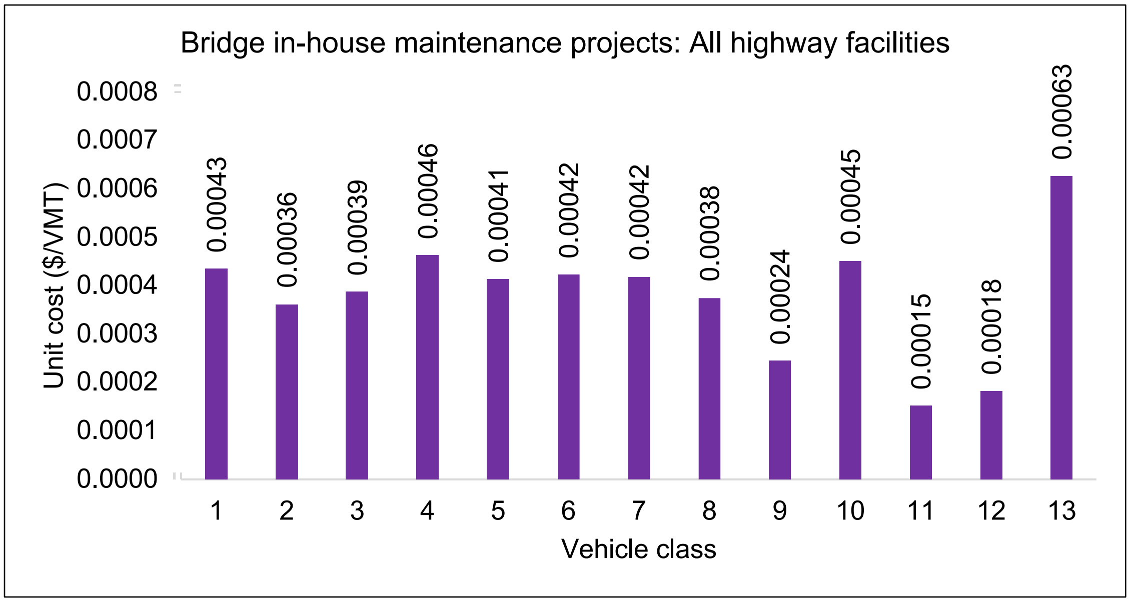


Figure 4.53: Unit cost ($/VMT) for bridge in-house maintenance projects on all highway facilities, 2014-2017.

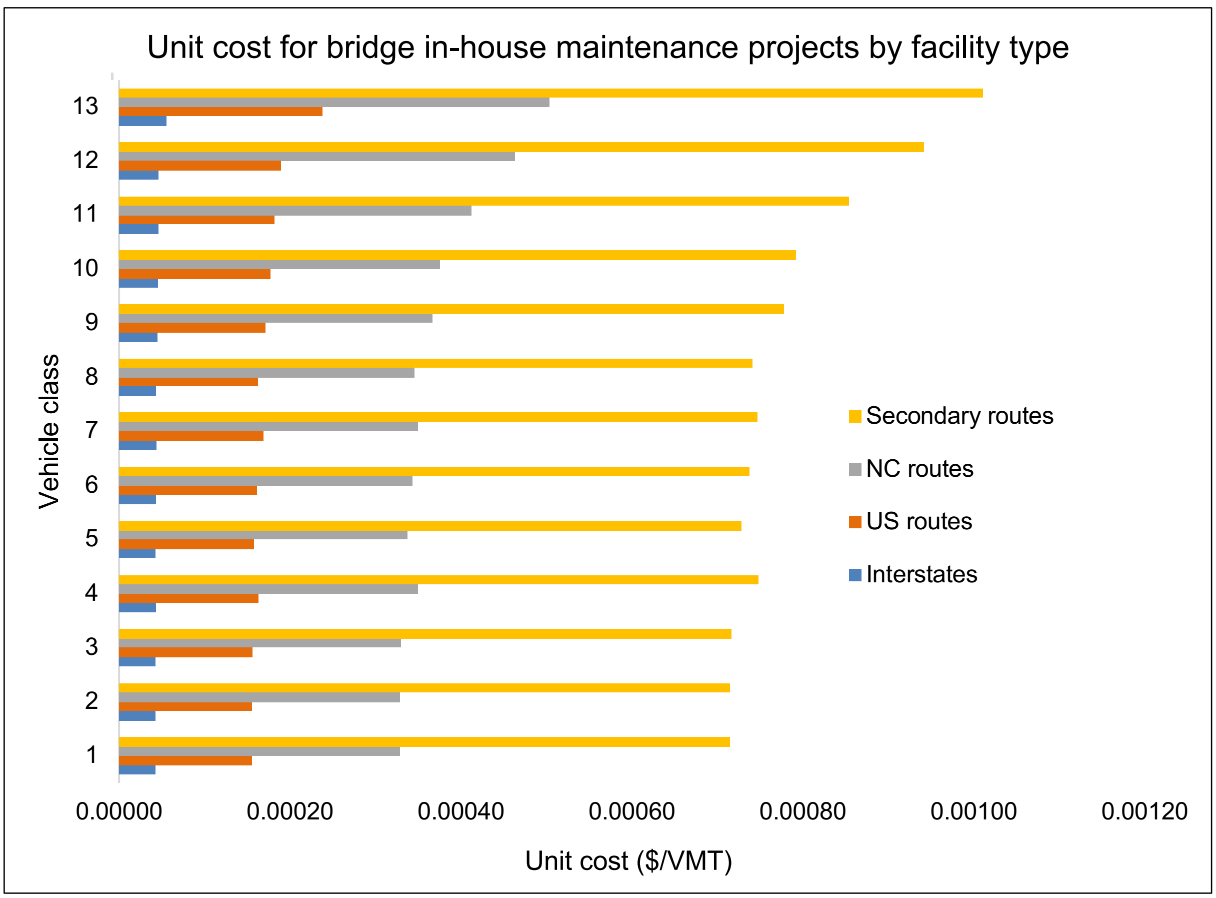


Figure 4.54: Unit cost ($/VMT) for bridge in-house maintenance projects by facility type and vehicle class, 2014-2017.

As seen from Figure 4.49 to Figure 4.54, class 13 vehicle has the highest unit cost on all highway facilities. The unit cost distributions for the other vehicle classes are similar across all four types of highway facilities. This is because a major portion of the in-house maintenance project costs are non-load related and allocated based on VMT.

4.4 Other Pavement and Bridge Related Projects

4.4.1 Safety, Traffic and Landscaping

This category includes traffic operation related projects, weigh station related projects, and safety, sign, and control related works of type 5 listed under "Other" projects on pavement and bridge structures. Out of 196 projects, 186 were pavement related and 10 were bridge related. These costs are distributed based on the PCE-miles on respective facilities, i.e., interstate, US, NC, SR and mixed. For mixed facilities, the average PCE-mile distribution for US, NC and SR is used. Approximately $143.64 million is allocated to the 13 vehicle classes on five types of highway facilities. Pavement related projects cost $141.76 million, and bridge related project were $1.88 million. Table 4.38 and Table 4.39 present the annual expenditures on these projects for interstate, US, NC, SR, and mixed routes.

Table 4.38: Costs ($Millions) by year and highway facility type for other pavement related projects.

Year	Interstate	US	NC	SR	Mixed	Total
2014	9.61	24.78	4.84	3.22	13.30	55.75
2015	1.30	5.10	1.42	2.00	0.40	10.22
2016	2.56	2.31	4.83	5.82	13.19	28.71
2017	4.84	4.11	1.12	33.04	3.96	47.07
Total by Facility	18.31	36.31	12.21	44.09	30.84	141.76
Average	4.58	9.08	3.05	11.02	7.71	

Table 4.39: Costs ($Millions) by year and highway facility type for Other bridge related projects.

Year	Interstate	US	NC	SR	Mixed	Total
2014	0.00	0.00	0.00	0.26	0.00	0.26
2015	1.36	0.01	0.00	0.00	0.00	1.37
2016	0.03	0.05	0.00	0.17	0.00	0.25
2017	0.00	0.00	0.00	0.00	0.00	0
Total by Facility	1.39	0.06	0.00	0.43	0.00	1.88
Average	0.35	0.02	0.00	0.11	0.00	

As seen in Table 4.38 and Table 4.39, secondary routes have the highest expenditures ($44.52 million), and NC routes have the least ($12.21 million) for "Other" projects on pavements and bridges. These costs have been allocated based on PCE-miles, and the results for pavement and bridge related "Other" projects' cost allocation are shown in Table 4.40 and Table 4.41, respectively.

Table 4.40: Distribution of Other Pavement Related Costs among Vehicle Classes ($).

Vehicle Class		Interstate	US	NC	SR	Mixed	All Facility	All Facility (%)
MC	**1**	64,504	172,434	63,583	321,203	172,009	793,733	0.56%
Cars	**2**	11,465,401	24,985,121	8,474,322	29,415,631	21,112,552	95,453,027	67.33%
2A4T	**3**	2,383,276	5,985,447	2,095,929	7,954,515	5,281,998	23,701,165	16.72%
Bus	**4**	179,014	410,800	136,191	840,125	410,985	1,977,115	1.39%
2ASU	**5**	667,211	1,728,971	600,111	2,566,048	1,571,357	7,133,696	5.03%
3ASU	**6**	205,375	442,278	146,381	735,140	410,687	1,939,860	1.37%
4ASU	**7**	10,069	55,164	16,790	57,060	43,539	182,621	0.13%
4AST	**8**	263,471	520,818	164,425	572,378	422,274	1,943,367	1.37%
5AST	**9**	2,940,276	1,824,642	468,598	1,438,328	1,283,902	7,955,746	5.61%
6AST	**10**	38,328	108,555	32,792	141,020	90,830	411,525	0.29%
5AMT	**11**	58,449	35,718	4,803	7,266	17,586	123,823	0.09%
6AMT	**12**	26,786	13,879	2,161	4,711	7,432	54,969	0.04%
7AMT	**13**	6,262	22,669	6,459	33,997	19,491	88,879	0.06%
Total		18,308,420	36,306,497	12,212,545	44,087,424	30,844,640	141,759,526	100%

Table 4.41: Distribution of Other Bridge Related Costs among Vehicle Classes ($).

Vehicle Class		Interstate	US	NC	SR	Mixed	All Facility	All Facility (%)
MC	**1**	5,422	293	-	3,105	-	8,819	0.47%
Cars	**2**	963,683	42,444	-	284,339	-	1,290,466	68.80%
2A4T	**3**	200,318	10,168	-	76,890	-	287,376	15.32%
Bus	**4**	8,901	698	-	8,121	-	17,720	0.94%
2ASU	**5**	33,176	2,937	-	24,804	-	60,918	3.25%
3ASU	**6**	10,212	751	-	7,106	-	18,069	0.96%
4ASU	**7**	501	94	-	552	-	1,146	0.06%
4AST	**8**	13,101	885	-	5,533	-	19,518	1.04%
5AST	**9**	146,203	3,100	-	13,903	-	163,206	8.70%
6AST	**10**	1,906	184	-	1,363	-	3,453	0.18%
5AMT	**11**	2,906	61	-	70	-	3,037	0.16%
6AMT	**12**	1,332	24	-	46	-	1,401	0.07%
7AMT	**13**	311	39	-	329	-	678	0.04%
Total		1,387,971	61,677	-	426,160	-	1,875,808	100%

Table 4.40 and Table 4.41 show that the largest share (about 67% to 69%) of the cost responsibility falls on class 2 or passenger car vehicles, as they have the largest VMT shares on all highway facilities.

4.4.2 Other In-House Maintenance Costs

Apart from the pavement and bridge related in-house maintenance work, some in-house maintenance work is classified as “Other” by NCDOT. These expenditures are allocated in the same fashion as the pavement and bridge related in-house maintenance projects. However, these are considered for both pavement and bridge related expenditures. Table 4.41 presents these in-house maintenance costs by year and facility types.

Table 4.42: Total cost ($Millions) by year and facility type for other in-house maintenance projects, 2014-2017.

Year	Interstate	US	NC	Secondary	Total by Year
2014	0.31	1.30	2.65	6.43	10.69
2015	0.15	0.61	1.25	3.03	5.03
2016	0.17	0.72	1.27	3.59	5.76
2017	0.13	0.55	0.93	2.72	4.33
Total by Facility	0.76	3.18	6.10	15.78	25.82
Average annual by facility type	0.19	0.79	1.53	3.94	

Costs from the other in-house maintenance projects are not divided into load and non-load related portions. All costs are allocated based on the PCE-miles.

Table 4.43 and Table 4.44 present the cost responsibility and unit costs for other in-house maintenance projects, respectively.

Table 4.43: Cost responsibility ($) by facility type and vehicle class for other in-house maintenance projects, 2014-2017.

Vehicle Class		Interstate	US	NC	SR	All Facility	All Facility (%)
MC	**1**	2960.3	15095.0	31782.3	114933.1	164770.7	0.64%
Cars	**2**	526181.3	2187210.6	4235906.6	10525537.2	17474835.7	67.69%
2A4T	**3**	109375.6	523969.2	1047654.5	2846294.5	4527293.7	17.54%
Bus	**4**	4860.2	35961.7	68075.4	300614.7	409512.0	1.59%
2ASU	**5**	18114.7	151355.0	299966.5	918186.3	1387622.6	5.38%
3ASU	**6**	5575.9	38717.2	73168.8	263048.7	380510.6	1.47%
4ASU	**7**	273.4	4829.1	8392.4	20417.3	33912.2	0.13%
4AST	**8**	7153.2	45592.7	82188.2	204809.0	339743.2	1.32%
5AST	**9**	79828.2	159730.1	234229.6	514664.4	988452.4	3.83%
6AST	**10**	1040.6	9503.0	16391.0	50460.0	77394.6	0.30%
5AMT	**11**	1586.9	3126.8	2400.7	2600.0	9714.4	0.04%
6AMT	**12**	727.2	1215.0	1080.0	1685.8	4708.0	0.02%
7AMT	**13**	170.0	1984.5	3228.6	12165.0	17548.1	0.07%
Total Cost		757848	3178290	6104465	15775416	25,816,018	100%

Table 4.44: Unit cost of travel in $/VMT from other in-house maintenance costs.

Vehicle Class		Interstate	US	NC	SR	All Facility
MC	1	0.000007	0.000027	0.000072	0.000087	0.000060
Cars	2	0.000007	0.000027	0.000072	0.000087	0.000052
2A4T	3	0.000007	0.000027	0.000072	0.000087	0.000055
Bus	4	0.000010	0.000059	0.000159	0.000192	0.000132
2ASU	5	0.000010	0.000059	0.000159	0.000192	0.000125
3ASU	6	0.000010	0.000059	0.000159	0.000192	0.000124
4ASU	7	0.000010	0.000059	0.000159	0.000192	0.000126
4AST	8	0.000011	0.000059	0.000159	0.000192	0.000114
5AST	9	0.000011	0.000059	0.000159	0.000192	0.000071
6AST	10	0.000011	0.000059	0.000159	0.000192	0.000125
5AMT	11	0.000011	0.000059	0.000159	0.000192	0.000044
6AMT	12	0.000011	0.000059	0.000159	0.000192	0.000047
7AMT	13	0.000011	0.000059	0.000159	0.000192	0.000133

4.4.3 Right of Way Cost

Total expenditures on Right of Way (RoW) purchases were $352.3 million, $391.9 million, $352 million, and $258.5 million for state fiscal years (SFY) 2014, 2015, 2016, and 2017, respectively. The RoW costs were not provided by the NCDOT expenditure data. The research team extracted the targeted expenditures on RoW purchases for each of the fiscal years from NCDOT's monthly financial update documents. Some of the recent highway cost allocation studies, including Indiana (Volovski et al., 2015) and Oregon (ECONorthwest, 2019), allocated the RoW costs among all user groups. These costs are allocated based on the PCE-miles following Indiana and Oregon's highway cost allocation study.

Table 4.45: Allocation of Right of Way costs ($Millions).

Vehicle class		Cost share	Cost share (%)
MC	1	7.56	0.56%
Cars	2	924.96	68.28%
2A4T	3	226.62	16.73%
Bus	4	17.70	1.31%
2ASU	5	63.16	4.66%
3ASU	6	17.28	1.28%
4ASU	7	1.57	0.12%
4AST	8	17.10	1.26%
5AST	9	72.75	5.37%
6AST	10	3.61	0.27%
5AMT	11	1.11	0.08%
6AMT	12	0.50	0.04%
7AMT	13	0.78	0.06%
Total Cost		1354.70	100%

4.5 Combined Results of Cost Allocation

This section combines the cost allocation from all types of pavement and bridge related projects. Table 4.46 presents the total pavement expenditures from all types of pavement related projects, allocated to 13 vehicle classes. Table 4.47 presents the total bridge expenditures from all types of bridge related projects allocated to 13 vehicle classes.

Table 4.46: Cost responsibility ($Millions) by project type and vehicle class for all pavement related projects, 2014-2017.

Vehicle Class		Project Types				Total	% Share
		New	Rehabilitation	In-House Maintenance	Other		
MC	1	2.20	4.37	8.07	0.79	15.44	0.31%
Cars	2	313.25	492.63	847.51	95.45	1748.84	34.99%
2A4T	3	118.72	190.61	225.89	23.70	558.92	11.18%
Bus	4	9.84	117.42	21.47	1.98	150.71	3.02%
2ASU	5	32.73	262.69	60.13	7.13	362.67	7.26%
3ASU	6	12.38	135.63	22.13	1.94	172.08	3.44%
4ASU	7	2.05	26.95	2.86	0.18	32.04	0.64%
4AST	8	13.98	122.83	19.23	1.94	157.98	3.16%
5AST	9	149.49	1315.82	131.20	7.96	1604.47	32.10%
6AST	10	4.45	105.41	11.44	0.41	121.71	2.44%
5AMT	11	2.99	16.09	0.92	0.12	20.12	0.40%
6AMT	12	1.05	6.74	0.48	0.05	8.33	0.17%
7AMT	13	1.38	39.02	4.01	0.09	44.49	0.89%
Total		664.51	2836.19	1355.33	141.76	4997.79	100%

Table 4.47: Cost responsibility ($Millions) by project type and vehicle class for all bridge related projects, 2014-2017.

Vehicle Class		Project Types				Total	% Share
		New	Rehabilitation	In-House Maintenance	Other		
MC	1	1.46	2.90	1.19	0.01	5.56	0.32%
Cars	2	259.42	321.60	121.19	1.29	703.50	40.94%
2A4T	3	79.97	108.78	31.81	0.29	220.85	12.85%
Bus	4	38.50	36.91	1.44	0.02	76.87	4.47%
2ASU	5	30.77	41.71	4.60	0.06	77.14	4.49%
3ASU	6	17.44	19.36	1.30	0.02	38.11	2.22%
4ASU	7	3.15	2.94	0.11	0.00	6.21	0.36%
4AST	8	230.99	18.92	1.12	0.02	251.05	14.61%
5AST	9	45.77	145.18	3.40	0.16	194.51	11.32%
6AST	10	43.45	19.44	0.28	0.00	63.17	3.68%
5AMT	11	9.62	3.76	0.03	0.00	13.42	0.78%
6AMT	12	6.44	3.18	0.02	0.00	9.64	0.56%
7AMT	13	34.32	23.75	0.08	0.00	58.15	3.38%
Total		801.30	748.43	166.58	1.88	1718.19	100%

Apart from Table 4.46 and Table 4.47, some other in-house maintenance expenditures are considered common for bridge and pavement structures. This includes the Other in-house maintenance projects (section 4.4.2), and Right of Way costs (section 4.4.3). We combined these expenditures with the expenditures from Table 4.46 and Table 4.47, and Table 4.48 demonstrates all the expenditures on roadway infrastructures.

Table 4.48: Cost responsibility ($Millions) by project type and vehicle class for all projects, 2014-2017.

Vehicle Class		Pavement related	Bridge related	Other in-house maintenance	Right of Way purchase	Total cost responsibility	Cost responsibility (%)
MC	**1**	15.44	5.56	7.56	0.16	28.72	0.35%
Cars	**2**	1748.84	703.50	924.96	17.47	3394.78	41.93%
2A4T	**3**	558.92	220.85	226.62	4.53	1010.92	12.49%
Bus	**4**	150.71	76.87	17.70	0.41	245.69	3.03%
2ASU	**5**	362.67	77.14	63.16	1.39	504.35	6.23%
3ASU	**6**	172.08	38.11	17.28	0.38	227.84	2.81%
4ASU	**7**	32.04	6.21	1.57	0.03	39.85	0.49%
4AST	**8**	157.98	251.05	17.10	0.34	426.48	5.27%
5AST	**9**	1604.47	194.51	72.75	0.99	1872.71	23.13%
6AST	**10**	121.71	63.17	3.61	0.08	188.56	2.33%
5AMT	**11**	20.12	13.42	1.11	0.01	34.66	0.43%
6AMT	**12**	8.33	9.64	0.50	0.00	18.47	0.23%
7AMT	**13**	44.49	58.15	0.78	0.02	103.44	1.28%
Total		**4997.79**	**1718.19**	**1354.70**	**25.82**	**8096.50**	

Figure 4.55 and Figure 4.56 show the distribution of allocated total costs, unit travel costs ($/VMT) and % share of VMT for 13 FHWA vehicle classes for pavement and bridge related projects, respectively. Figure 4.57 shows distribution of allocated costs by vehicle class combined for all types of projects.

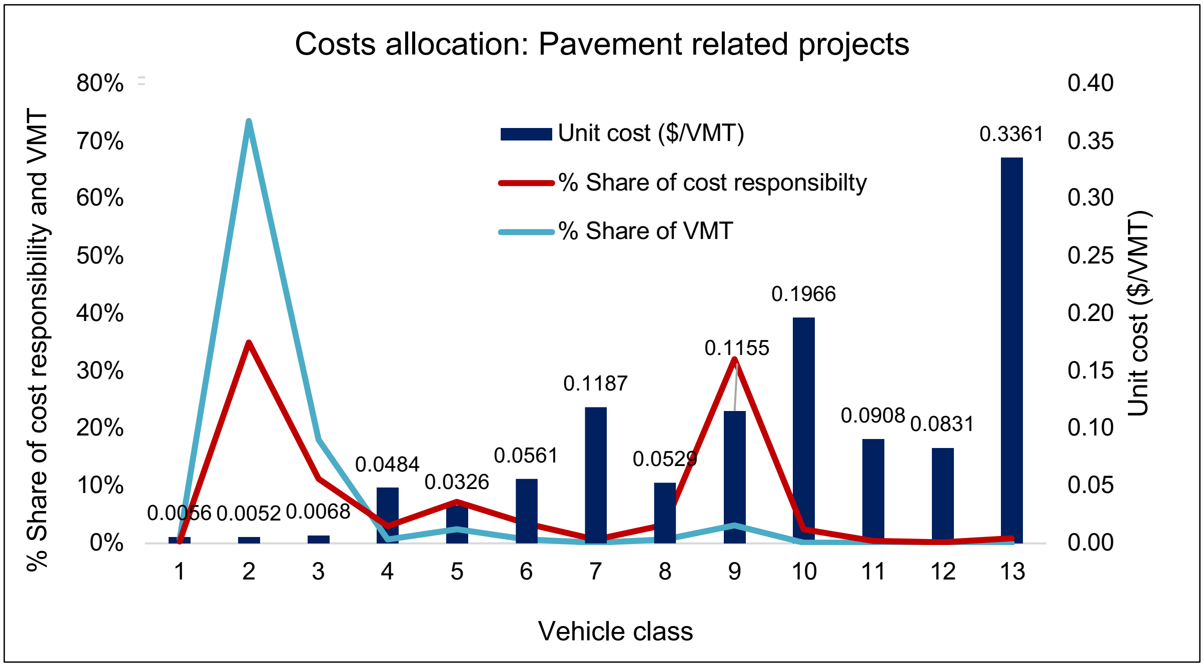


Figure 4.55: Cost allocation by vehicle class for pavement related projects.

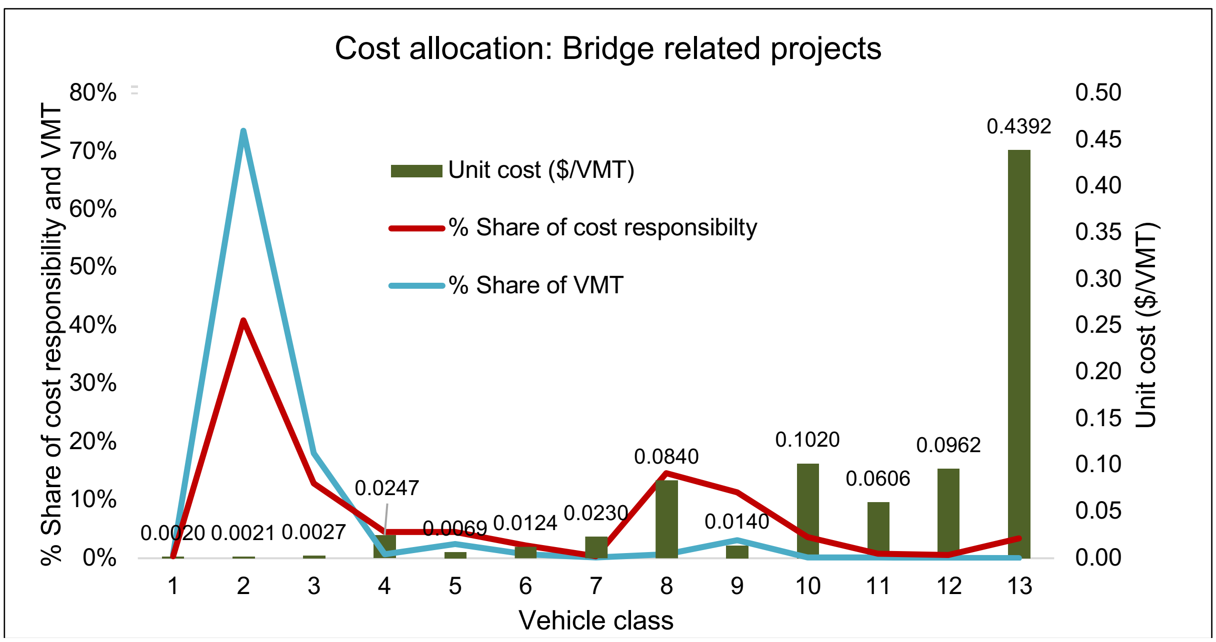


Figure 4.56: Cost allocation by vehicle class for bridge related projects.

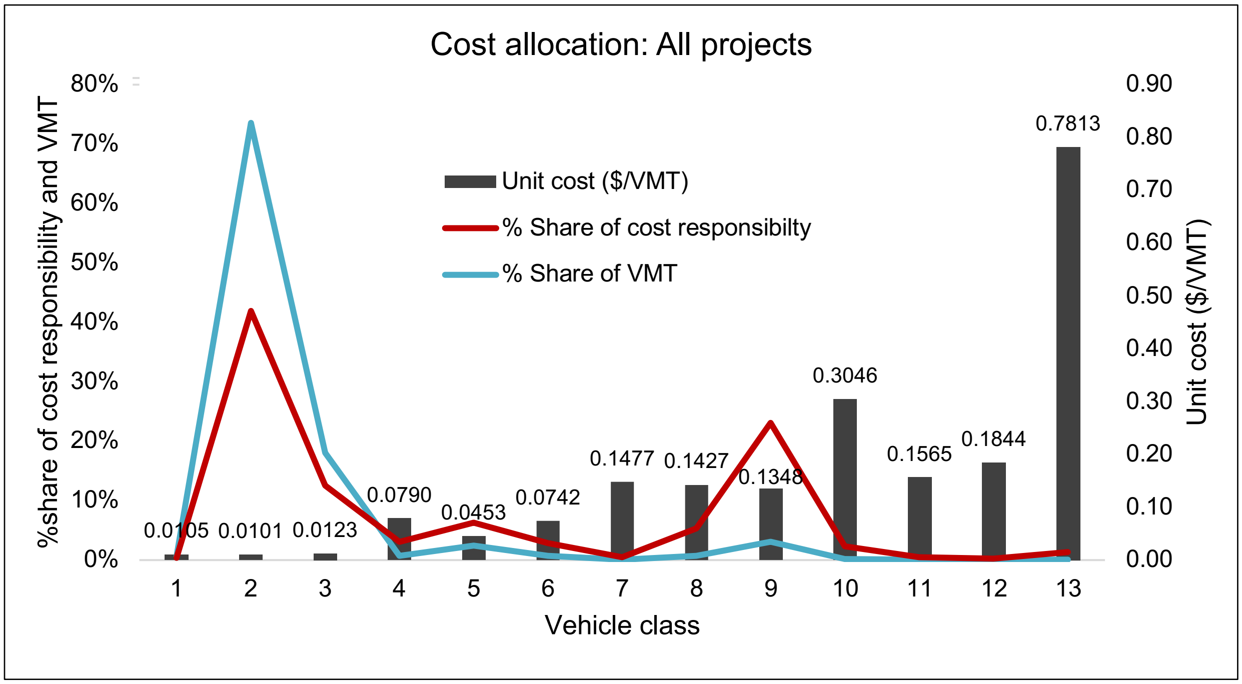


Figure 4.57: Cost allocation by vehicle class for all projects.

From the Table 4.48 and Figure 4.57, we see that the passenger car has the highest percentage of cost responsibility of 41.93%. Among the trucks, FHWA class 9 (5-axle tractor semitrailer) has the highest cost responsibility at 23.13%. Other states' HCASs showed similar trends (see Table 4.49 and Figure 4.58). For instance, Indiana (Volovski et al., 2015) and Minnesota (Gupta, 2012) allocated 43.12% and 38.76% of the total cost responsibility to passenger cars, respectively. Nevada (Balducci et al., 2009) and Idaho (Balducci et al., 2010) allocated 55.30% and 22.38% of the total cost to passenger cars, respectively. Among the truck traffic, Indiana, Minnesota, and Nevada reported highest percentage to FHAW class 9 vehicles, with 25.16%, 20.89%, and 23.48% of the total cost, respectively. Figure 4.57 shows that the unit cost for the non-trucks, i.e., motorcycle, passenger vehicles, and pickup trucks, is very low compared to the trucks, implying the trucks are causing more damage per mile of travel compared to non-trucks. The unit cost of travel for passenger cars is $0.010 in NC, compared to $0.026 in Indiana, $0.015 in Minnesota, $0.022 in Nevada, and $0.028 in Idaho (Balducci et al., 2010; Balducci et al., 2009; Gupta, 2012, Volovski et al., 2015). Among the single unit trucks (FHWA class 4-7), vehicle class 7 has the highest unit costs in pavement related projects, and vehicle class 8 has the highest unit cost in bridge related projects. For multi-unit trucks, class 13 vehicles have a very low percentage share of cost responsibility but the highest unit costs. These vehicles cause the most damage per mile of travel to the pavement compared to other classes of vehicles. Indiana, Nevada, and Minnesota also reported the highest unit cost for FHWA class 13 vehicles.

Table 4.49: Share of total cost allocated to FHWA vehicle classes in state HCAS report.

Vehicle class	Indiana	Minnesota	Nevada	NC
1	0.4%	0.0%	0.0%	0.4%
2	43.1%	38.8%	55.3%	41.9%
3	17.8%	23.8%	0.0%	12.5%
4	0.4%	0.7%	3.0%	3.0%
5	3.3%	3.7%	4.8%	6.2%
6	3.3%	2.2%	2.3%	2.8%
7	3.6%	1.4%	0.0%	0.5%
8	1.7%	1.1%	1.5%	5.3%
9	25.2%	20.9%	23.5%	23.1%
10	0.5%	6.8%	0.9%	2.3%
11	0.3%	0.3%	2.9%	0.4%
12	0.1%	0.1%	0.9%	0.2%
13	0.3%	0.3%	3.0%	1.3%

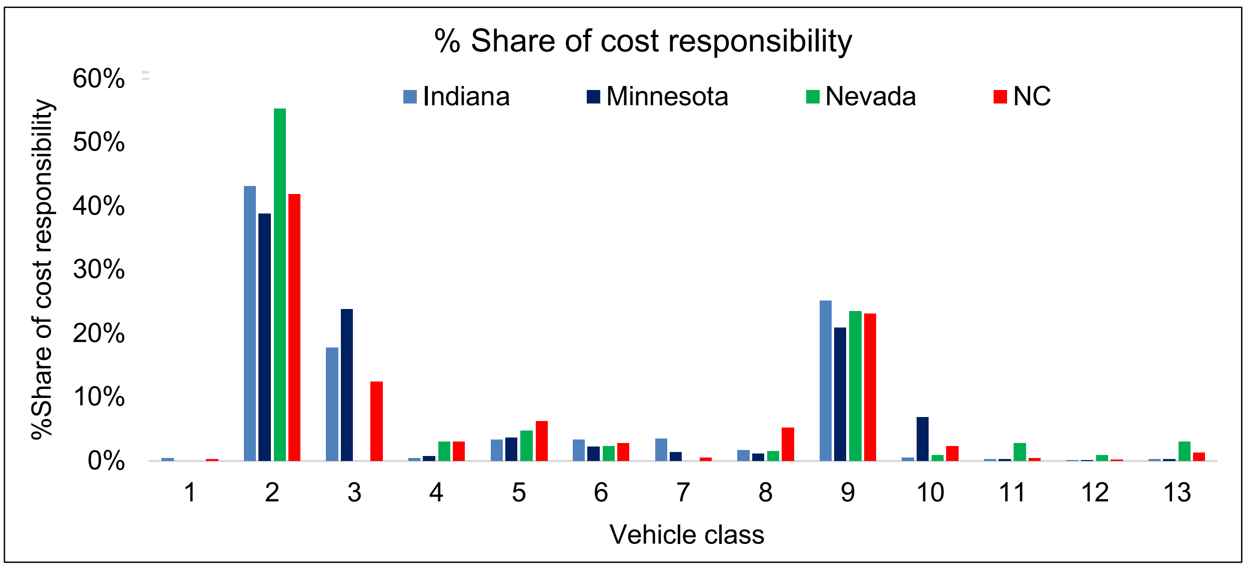


Figure 4.58: Percentage share of cost responsibility by FHWA vehicle class for HCAS study across states.

4.6 Limitations

The primary limitations of the cost allocation analysis pertain to the lack of detail in contract information and up-to-date traffic data. The annual VMT data from NCDOT are provided by FHWA roadway functional classes. The FHWA HCAS tool also requires VMT and cost data to be input according to FHWA functional classes. However, the location description in the contract data is in interstate, US, NC or secondary route format. As a result, the research team had to use route-mile information to distribute the VMTs from one roadway functional class to another roadway functional class. The research team believes this might have impacted the results.

Additionally, contract description of the other projects did not include details about the type of pavement structure (flexible or rigid), except for new pavement construction projects. The research team could not find the detail documents (i.e., RFP or request for proposal) for all the new construction projects, which could have helped to determine the types of structural layers and their thickness. Some contract data did not include the details of all the work items, which made it difficult to estimate the load-related and non-load related costs of the project.

Finally, NCDOT's WIM data did not include enough samples for NC and secondary routes. Therefore, the default FHWA operating GVW were used for NC and Secondary routes. FHWA developed this distribution using WIM data from a few sample sites located on several western states. Therefore, this data is not an ideal representative sample for state and Secondary routes of North Carolina. The research team also could not find axle weight distribution for the highway facilities of North Carolina. Therefore, the default axle weight distribution included in the FHWA HCAS tool is used for cost allocation purposes.

5 Revenue Attribution

5.1 Revenue Sources

Major revenue sources used in HCAS of other states include revenue collected by the federal, state and local governments. Table 5.1 summarizes the revenue sources used in other state HCASs.

Table 5.1: Revenue sources included in recent HCAS studies of other states.

State HCAS Study	Federal Revenue	State Revenue	Local Revenue
Oregon (ECONorthwest, 2019)	N/A	Fuel, registration, title, other motor carrier revenue, road use assessment fee, weight-mile tax.	N/A
Nevada (P Balducci et al., 2009)	Gasoline Tax, special fuel tax, heavy vehicle use tax, truck and trailer sales tax, tire tax.	Registration fees, ad-valorem (Governmental Service Tax fees) taxes, motor fuel taxes, driver's license fees, and vehicle sales taxes.	N/A
Texas (Luskin et al., 2002)	Fuel tax, sales tax on heavy trucks and trailers, heavy vehicle use tax and tire sale tax.	Registration fees, fuel tax and motor oil taxes	N/A
Idaho (Balducci et al., 2010)	Gasoline tax, special fuel tax, heavy vehicle use tax, truck and trailer sales tax, tire tax.	Gasoline tax, special fuel tax, vehicle registration fee, overweight fee, oversized fee, title fee, driver's license fees.	Local option registration fee, Local license administrative fee.
Indiana (Volovski et al., 2015):	Gasoline tax, diesel tax, Heavy vehicle use tax, Excise tax on trucks and trailers, tires	Gasoline tax, diesel tax, registration fees, international registration plan, motor carrier fuel use tax, motor carrier surcharge tax, and oversize/overweight permits.	Commercial vehicle excise tax, wheel tax, motor vehicle excise tax and excise surtax.

5.1.1 Transportation Infrastructure Revenue - NCDOT

Seventy-five percent of the funding for transportation expenses covered by NCDOT comes from state revenue sources, and the remaining 25% comes from federal revenue sources. The NCDOT has two main funds to cover the transportation financing needs of the state: the Highway Fund, which includes approximately 60% of the total revenue, and the Trust Fund, which includes approximately 40% of the revenue. The Highway Fund finances operation and maintenance projects, the DMV, and administrative costs. The Trust Fund finances capital construction projects, debt/GAP fund, work related to NC Ports, and administrative costs. Federal revenue can only be allocated to the Trust Fund, while state revenue contributes to both funds.

5.1.1.1 Federal Revenue Sources

Federal revenue sources include:

i. Gasoline and special fuel tax: Federal gas taxes are collected at a rate of 18.4 cents per gallon of gasoline and 24.4 cents per gallon of diesel.

ii. Federal use tax: This tax is charged on top of the sales tax for new vehicles. Sales taxes are collected at a rate of 12% of retail price for trucks over 33,000 lbs. of gross vehicle weight (GVW) and for trailers over 26,000 lbs. of GVW. On top of the sales tax, the trucks over 55,000 lbs. are charged with a federal use tax. The rate is $100 for every truck over 55,000 lbs. plus additional $22 for each 1,000 lbs. but not exceeding $550.

iii. Tax on trucks and trailers

iv. Tire tax: Tire tax is charged at a rate of 9.45 cents ($.04725 in the case of a biasply tire or super single tire) for each 10 lbs. of the maximum rated load capacity over 3,500 lbs.

Table 5.2 presents the federal revenue collected during the study period (2014 to 2017). All amounts in Table 5.2 represent the revenue collected during federal government's fiscal year, which runs from October 1 of the previous year to September 30 of the analysis year.

Table 5.2: Collected revenues ($Millions) by year from federal revenue sources.

	2014	2015	2016	2017
Gasoline Tax	662.61	668.04	707.66	729.61
Special Fuels Tax	214.58	221.11	223.08	238.19
Federal Use Tax	24.31	29.82	31.32	32.51
Tax on Trucks and Trailers	93.75	118.11	112.48	84.03
Tire Tax	11.45	12.99	12.61	12.82
Total	**1,006.73**	**1,050.07**	**1,087.15**	**1,097.16**

*All values are for federal government fiscal year

5.1.1.2 State Revenue Sources

The three main sources of state revenue are motor fuel tax (50%), DMV fees (30%), and highway use tax (HUT; 20%). Figure 5.1 shows the revenue collections from federal and state revenue sources and their contributions to Highway Fund and Trust Fund.

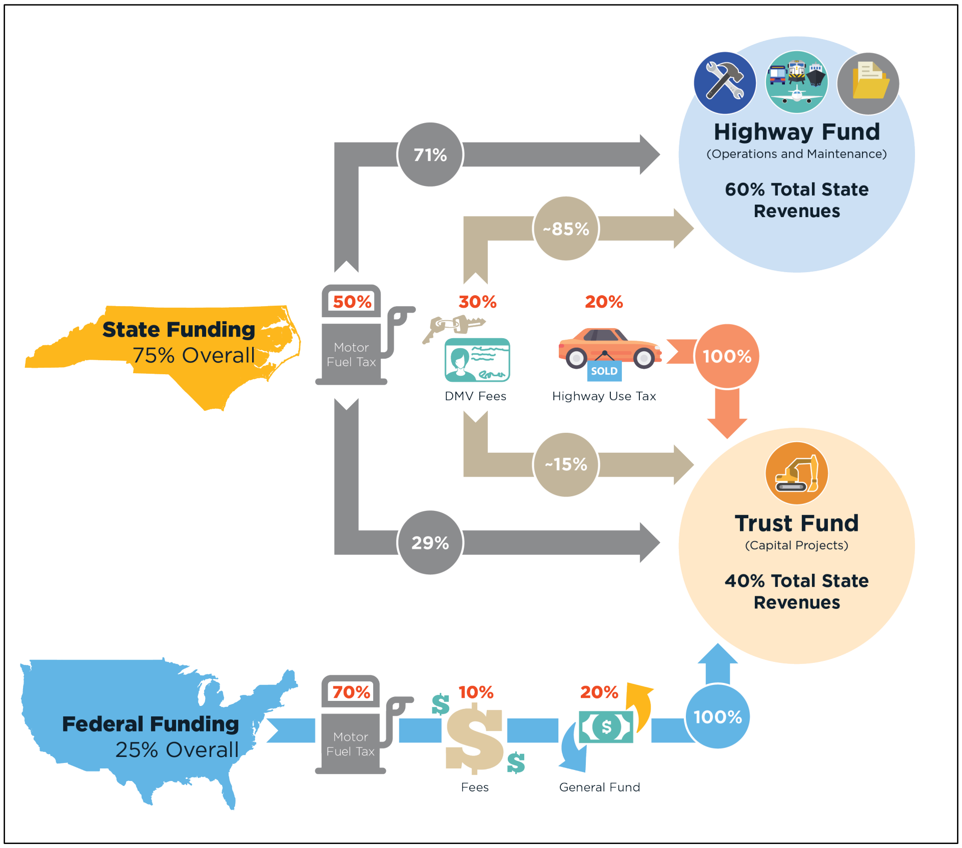


Figure 5.1: NCDOT's funding sources (Source: (H. Tasaico, 2020)).

5.1.1.2.1 Motor Fuel Tax

The state motor fuels tax includes a fixed amount of tax charged per gallon of fuel (both gasoline and diesel) and an additional 0.0025 cents per gallon inspection fee. The motor fuel tax and inspection fee contribute approximately 50% of the total state revenue. During the study period (2014-2017) the fuel tax rate fluctuated between 34.3 cents per gallon to 37.5 cents per gallon. Starting from January 1, 2017, the motor fuel tax rate was set at a flat rate of 34 cents per gallon, multiplied by a percentage. The percentage depends on the state's population change during the applicable calendar year and the percentage change in annual energy index in the Consumer Price Index for all urban consumers (NDOR, 2020). For revenue attribution purposes, 81% of the total state fuel tax is attributed to gasoline users, and the remaining 19% is attributed to special fuel (diesel) users.

5.1.1.2.2 Motor Vehicle Fees

Motor vehicle fees mainly consist of registration fees, license fees, title fees, and other miscellaneous fees. The various types of registration fees collected by NCDOT include staggered registration fee (fees for vehicles in FHWA classes 1-3), truck license (registration fees for trucks, i.e., FHWA classes 4-13), international registration plan fees, highway usage registration fees, and miscellaneous registration fees. Apart from drivers' license fees and title fees, the other types of motor vehicle revenue sources include gasoline inspection tax, auto safety equipment tax, exhaust emission inspection fees, motor carrier safety fees, dealers' and manufacturers' license fees, financial security restoration fees, lien recording fees, and overweight/size permit fees.

5.1.1.2.3 Highway Use Tax

North Carolina charges highway use tax (HUT) on vehicle purchases rather than a sales tax. This tax applies to all retail and casual sales of motor vehicles at the rate of 3% of purchase price. For new residents moving to North Carolina, the maximum HUT is $250, and for commercial (weighing more than 26,000 lbs.) and recreational vehicles, the maximum HUT is $2,000 (NC First Commission, 2020). The HUT contributes approximately 20% of the state revenue and covers 16% of NCDOT's annual budget.

Table 5.3, Table 5.4, and Table 5.5 present the total revenue under Highway Fund, Trust Fund, and combined state and federal revenue for the study period, respectively.

Table 5.3: Collected state revenue ($Millions) by year in the Highway Fund.

Revenue Source	**2014**	**2015**	**2016**	**2017**
Truck Licenses	139.70	143.54	195.54	197.21
Title Fee	0.77	0.82	0.76	0.76
Staggered Registration	204.95	208.42	274.15	280.78
Gas Tax	1404.34	1396.99	1329.11	1355.56
Gasoline Inspection Tax	14.07	14.73	15.13	15.65
Registration Fees	3.76	4.04	5.70	5.99
Driver License Fees	111.08	122.28	133.90	124.24
Auto Safety Equip. Inspection Fees	1.63	1.93	2.13	2.09
Financial Security Restoration Fees	3.35	1.46	0.44	0.73
Lien Recording Fees	0.09	0.26	0.28	0.33
Exhaust Emission Inspection	28.46	25.63	25.31	25.49
International Registration Plan Fees	59.10	62.93	115.68	100.88
Dealers' Manufacturers' License Fees	1.27	1.28	1.73	1.74
Process Service Fees	4.49	4.67	4.08	4.51
Overweight/Size Permits	5.91	6.32	6.64	7.04
Motor Carrier Safety Fees	0.10	0.07	0.06	0.07
Highway Usage Registration Fees	0.18	0.37	0.18	0.36
DMV Other Fees	2.99	5.27	3.03	6.36
Total	**1986.24**	**2000.99**	**2113.86**	**2128.99**

Table 5.4: Collected state revenue ($Millions) by year in the Trust Fund.

Revenue Source	2014	2015	2016	2017
Title Fee	84.41	89.44	121.13	123.17
Lien Recording	3.87	3.57	4.07	3.89
Gas Tax	470.99	525.30	554.05	564.03
Highway use Tax	620.14	692.35	760.60	785.31
Miscellaneous Registration Fees	11.17	12.10	15.57	15.65
Total	**1190.57**	**1322.76**	**1455.42**	**1492.05**

Table 5.5: Combined revenue ($Millions) by year from federal and state revenue sources.

Revenue Source	2014	2015	2016	2017
Federal	1007	1050	1087	1097
State (HF)	1986	2001	2114	2129
State (HTF)	1191	1323	1455	1492
Total Annual	4184	4374	4656	4718
Total of 4 year	**17931.97**	Average annual revenue		**4482.99**

Total revenue collected from 2014 to 2017 is $17.93 billion, with average annual revenue of $4.48 billion. Please note that the total cost allocated summed up to $8.1 billion over the 4-year period (Table 4.48) with an annual average of $2.02 billion, as in the cost allocation section, we did not incorporate the expenditures on sectors such as debt payment services, state agency transfers, administrative costs, payments to professional engineering and construction contracts, and costs for other modes i.e., aviation, rail, ferries, public transit, and bikes.

5.2 Revenue Attribution

Revenues are allocated by vehicle class using either the percentages of VMT or the number of registered vehicles. For instance, to distribute the fuel tax, the percentages of fuels used by vehicle class are determined using the VMT and respective fuel efficiencies. These values are then used to distribute fuel tax revenues to all the vehicle classes. Some of the revenues, including registration fees, title fees, driver license fees, and other revenues, are distributed based on the number of registered vehicles.

Table 5.6 shows the average annual revenue collected from the state and federal revenue sources and their allocation methods.

Table 5.6: Average collected revenue ($Millions) for the period 2014-2017 by source and attribution method.

Source of revenue	HF/TF or Federal*	Collected revenue	Attribution method
State Gasoline Tax	HF & TF	1539.08	By VMT to non-trucks (FHWA vehicle class 1 – 3)
Highway Use Tax	TF	714.60	By number of registered vehicles
Federal Gasoline Tax	Federal	691.98	By VMT to non-trucks (FHWA vehicle class 1 – 3)
State Diesel Tax	HF & TF	361.02	By VMT to trucks (FHWA class 4 –13)
Staggered Registration	HF	242.07	By number of registered vehicles in FHWA class 1-3 and accounting for higher fees for classes 2 and 3 (~1.52 times higher compared to class 1)
Federal Special Fuel Tax	Federal	224.24	By VMT to trucks (FHWA class 4 –13)
Truck Licenses	HF	169.00	By vehicle registered weight to FHWA class 4-13.
Driver License Fees	HF	122.88	By number of registered vehicles (regular license to vehicles FHWA class 1-3, commercial license to vehicles FHWA class 4-13.)
Title Fee	TF & HF	105.32	By number of registered vehicles
Federal Truck & Trailers Fee	Federal	102.09	By number of registered vehicles in FHWA class 4-13.
International Registration Plan Fees	HF	84.45	By VMT to trucks (FHWA class 4 –13)
Federal Heavy Vehicle Use Tax	Federal	29.49	By number of trucks with registered weight over 55,000 lbs.
Exhaust Emission Inspection	HF	26.22	By number of registered vehicles
Gas inspection tax	HF	14.90	By VMT
Miscellaneous Registration Fees	TF	13.62	By number of registered vehicles in FHWA class 1-3
Federal Tire Tax	Federal	12.48	By number of registered vehicles in FHWA class 4-13.
Overweight/Size Permits	HF	6.48	By vehicle registered weight to trucks (FHWA class 4-13).
Registration Fees	HF	4.87	By number of registered vehicles
Process Service Fees	HF	4.44	
DMV Other Fees	HF	4.41	
Lien Recording Fee	HF	4.09	

Auto Safety Equipment Fee	HF	1.95	
Dealers' Manufacturers' License Fees	HF	1.51	By number of registered vehicles in FHWA class 1-3
Financial Security Restoration Fees	HF	1.50	By number of registered vehicles
Highway Usage Registration Fees	HF	0.28	By number of registered vehicles
Motor Carrier Safety Fees	HF	0.07	By VMT to multi-unit trucks (FHWA class 8 –13)

**HF and TF correspond to Highway Fund and Trust Fund, respectively.*

Revenue from the federal and state fuel tax was allocated on the basis of VMT and an average fuel efficiency for each vehicle class (see Table 5.7).

Table 5.7: Fuel efficiency (miles per gallon) by vehicle class and by year. (source: (Bureau of Transportation Statistics, 2020))

Vehicle class	2014	2015	2016	2017	Average
1	43.5	43.8	43.9	44.0	43.8
2	23.2	23.9	24	24.2	23.8
3	17.1	17.3	17.4	17.5	17.3
4 to 7	7.2	7.3	7.3	7.3	7.3
8 to 13	5.8	5.9	5.9	6	5.9

The research team used two sets of vehicle registration data to allocate the revenues. The first data set included the number of registered vehicles by fiscal year and by vehicle types e.g., motorcycle, sedan, coupe, sports utility vehicle (SUV), van, trucks, tractor trailers and others. The research team classified these types as motorcycle (FHWA class 1), passenger cars (FHWA class 2), SUV (FHWA class 3), single-unit trucks (FHWA classes 4-7), and multi-unit trucks (FHWA classes 8-13). Next, the number of vehicles under single-unit trucks and multi-unit trucks were distributed among FHWA class 4-7 and FHWA class 8-13, respectively, based on the VMT distribution for these vehicle classes. This data set was used to attribute the revenue associated with the highway use tax. Vehicles with higher purchase cost have to pay higher amount as HUT. Due to lack of HUT data by vehicle class, the research team used average purchase price for the vehicle classes to distribute the highway use tax. The average purchase price for motorcycles, passenger cars, class 3 vehicles, single-unit, and multi-unit trucks were assumed to be $10,000, $35,000, $50,000, $85,000 and $165,000, respectively. Most of the motor vehicle fees were also attributed using the first data set, with a few exceptions discussed below.

To attribute the revenue from truck licenses, overweight/size permits, and federal heavy vehicle use tax, the research team used vehicle registration data with the number of registered vehicles by weight provided by the NCDMV. This data includes the number of registered vehicles into different weight bins starting from 4,000 lbs. to 80,000 lbs. Any vehicle registered with weights greater than 4,000 lbs. is considered a truck (FHWA vehicle classes 4-13). The vehicle registration fees vary for the following five weight categories:

- Up to 4,000 lbs.
- 4,001 to 9,000 lbs. inclusive
- 9,001 to 13,000 lbs. inclusive
- 13,001 to 17,000 lbs. inclusive
- 17,001 lbs. and over

There is no data on overweight and over-sized vehicles. We have assumed that overweight and over-sized vehicles are included in the 80,000 lbs. weight bin. We used the seven weight categories shown in Table 5.8 to attribute revenues associated with weight. Table 5.8 shows the percentage of registered vehicles in each weight category.

Table 5.8: Percentage share of registered vehicles by year and weight category.

		Percentage of registered vehicles				
Weight category	**Weight limit**	**2014**	**2015**	**2016**	**2017**	**Average (2014-2017)**
W1	<= 4,000 lbs.	88.66%	88.22%	87.71%	87.30%	87.96%
W2	4,001 to 9,000 lbs. inclusive	7.95%	8.31%	8.75%	9.09%	8.54%
W3	9,001 to 13,000 lbs. inclusive	1.34%	1.38%	1.42%	1.48%	1.41%
W4	13,001 to 17,000 lbs. inclusive	0.54%	0.55%	0.56%	0.56%	0.55%
W5	17,001 to 55,000 lbs. inclusive	1.28%	1.31%	1.32%	1.33%	1.31%
W6	55,001 to 75,000 lbs. inclusive	0.08%	0.09%	0.09%	0.09%	0.09%
W7	75,001 lbs. and over	0.14%	0.14%	0.14%	0.14%	0.14%

The total revenue contribution is reported by FHWA vehicle class. The revenues allocated among the weight groups from Table 5.8 were converted to the 13 FHWA vehicle classes based on expert opinion from Mr. Kent Tylor, Traffic Survey Engineer at NCDOT, and the upper limits of the GVW distribution of the different vehicle classes.

Specifically:

- All FHWA class 1, 2, and 3 vehicles are assumed to be registered in the W1 category
- 50% of the single-unit trucks are assumed to be registered in the W2 category
- 50% of FHWA class 4 and 6 vehicles are assumed to be registered in the W5 category
- 25% of FHWA class 7 vehicles are assumed to be registered in the W5 category, while the remaining 25% in W6
- 50% of FHWA class 5 vehicles are distributed in multiple categories (W3-W4) based on the upper values observed in the gross weight distribution, due to lack of other information.
- All FHWA class 11 and 12 vehicles are assumed to be registered in the W6 category
- All FHWA class 9, 10, and 13 vehicles are assumed to be registered in the W7 category
- 50% of FHWA class 8 vehicles are assumed to be registered in the W6 category, while the rest in W5.

5.3 Revenue Attribution Results

Table 5.9 presents the revenues by year, attributed to FHWA 13 vehicle classes. The highest percentage share of revenue (56.68%) was attributed to passenger cars. Indiana (Volovski et al., 2015), Minnesota (Gupta, 2012), and Idaho (Balducci et al., 2010) each attributed 47.43%, 52.37%, and 32.93% of the total revenues to passenger cars, respectively. FHWA class 3 vehicles have the second highest share of revenues at 13.59%. Among the multi-unit trucks, class 9 vehicles contributed the highest amount to the revenue (9.93% of the total revenue). Similar trends were reported by Indiana, Minnesota, and Nevada.

Table 5.9: Attributed revenues ($Millions) by FHWA vehicle class and year.

FHWA vehicle class	Annual revenue				Total revenue	Total revenue (%)
	2014	2015	2016	2017		
1	19.43	19.54	21.75	22.03	82.77	0.46%
2	2,224.97	2,309.41	2,442.88	2,492.97	9,470.22	52.81%
3	585.96	596.65	604.82	636.01	2,423.45	13.51%
4	126.68	150.12	170.42	169.41	616.63	3.44%
5	443.76	473.18	529.35	537.74	1,984.02	11.06%
6	140.74	143.80	163.33	159.60	607.47	3.39%
7	11.79	13.37	15.11	15.07	55.34	0.31%
8	115.05	121.06	131.65	129.48	497.25	2.77%
9	481.86	503.35	530.91	513.50	2,029.61	11.32%
10	18.08	24.26	25.45	22.69	90.48	0.50%

11	8.22	9.56	10.52	9.85	38.16	0.21%
12	4.01	4.26	4.70	4.30	17.28	0.10%
13	2.98	5.24	5.53	5.53	19.29	0.11%
Total	**4,183.54**	**4,373.81**	**4,656.43**	**4,718.20**	**17,931.97**	

Table 5.10 and Figure 5.2 compare the percentage share of revenues from FHWA vehicle classes found in HCASs in Indiana, Minnesota, and Nevada.

Table 5.10: Share of total revenue attributed to FHWA vehicle classes in state HCAS report.

Vehicle class	Indiana	Minnesota	Nevada	NC
1	0.42%	_	_	0.46%
2	47.43%	52.37%	78.90%	52.81%
3	20.64%	28.68%	0.00%	13.51%
4	0.38%	0.69%	1.79%	3.44%
5	3.11%	3.99%	3.69%	11.06%
6	2.22%	2.25%	1.89%	3.39%
7	3.10%	0.70%	_	0.31%
8	1.41%	0.98%	1.07%	2.77%
9	20.30%	7.56%	10.00%	11.32%
10	0.37%	2.47%	0.31%	0.50%
11	0.27%	0.14%	0.71%	0.21%
12	0.12%	0.05%	0.28%	0.10%
13	0.24%	0.13%	0.81%	0.11%

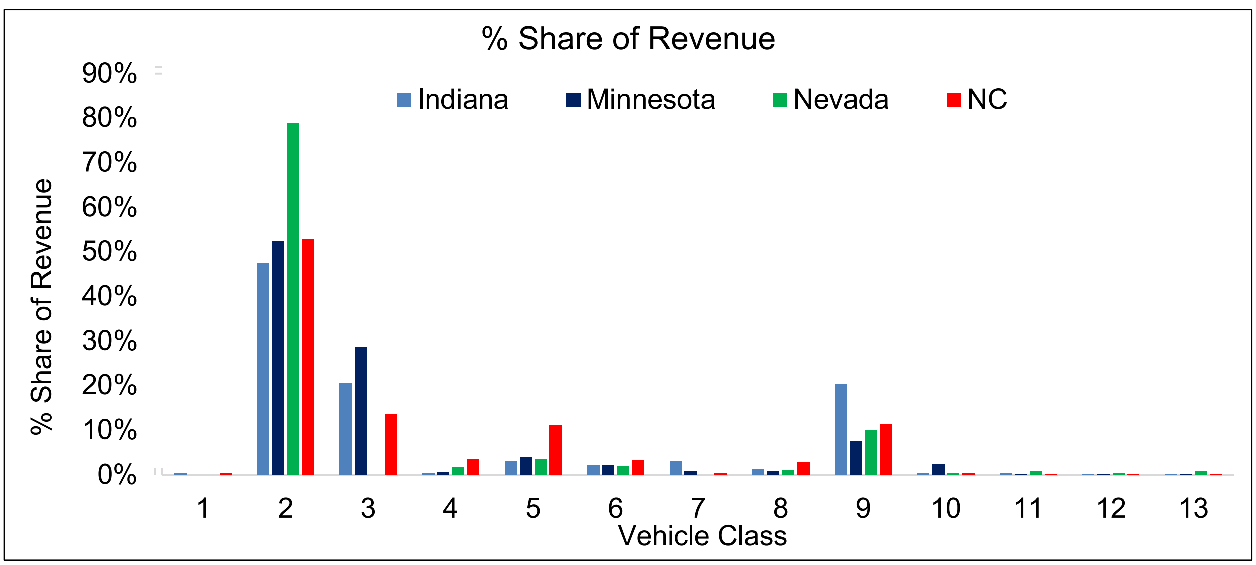


Figure 5.2: Percentage share of revenues by FHWA vehicle class for HCAS studies in four states.

Among the single-unit trucks, class 5 vehicles contributed the highest amount to the revenue (11.06% of the total revenue). This amount is higher than what has been reported in the other state HCAS reports (Figure 5.2) because during field data collection at the vehicle classification stations, NCDOT allots all the misclassified trucks under FHWA class 5. As a result, class 5 trucks have a higher VMT and higher number of registered vehicles among the single-unit trucks. Both VMT and the number of registered vehicles are key allocators to attribute revenue; hence, we have found higher than usual share of total revenues to class 5 vehicles.

5.4 Limitations

A significant portion of the collected revenues are allocated in terms of the number of registered vehicles. Since the NCDOT does not have clear guidelines to distribute the registered trucks into FHWA class 4-13, the research team had to use the percentage of VMT to distribute single-unit trucks to FHWA class 4-7 and multi-unit trucks to FHWA class 8-13. This assumes that the number of registered trucks in each vehicle class is proportional to their VMT, which may not be the case. Revenues from several sources are attributed to the seven weight-based vehicle categories. The research team had to use some approximation to distribute the revenues attributed to the weight-based vehicle categories to the FHWA 13 vehicle classes. Revenues from overweight/size fees are attributed among all the trucks due to lack of detail information.

6 Equity Ratios

The equity ratio for each roadway user compares the portion of revenues attributed to the portion of expenditures allocated. It is defined as the ratio of the percentage of revenue contribution to the percentage share of cost responsibility.

$$Equity\ ratio = \frac{\%\ Share\ of\ Revenue}{\%\ Share\ of\ Cost\ Responsibility}$$

A vehicle with an equity ratio greater than one pays more than their cost-responsible share, while a vehicle with an equity ratio of less than one pays less than its cost-responsible share (ECONorthwest, 2019).

Table 6.1 and

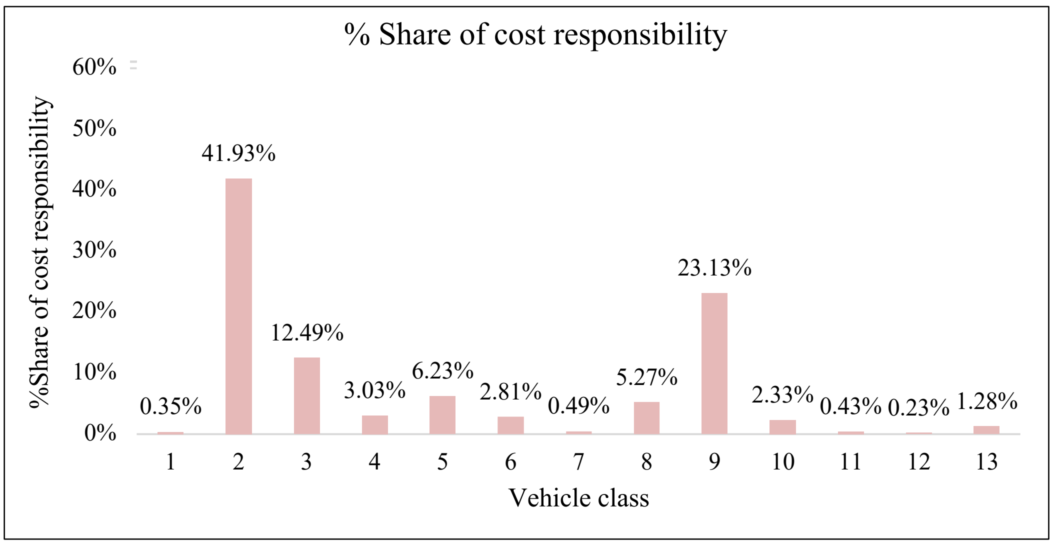
Table 6.2 present the equity ratios by the 13 FHWA vehicle classes and NCDOT's 5 vehicle classification system, respectively. The percentage cost responsibility and revenue shares for FHWA classes 4-7 and classes 8-13 are combined to estimate the equity ratios for single-unit trucks and multi-unit trucks, respectively. Figure 6.1 and Figure 6.2 shows the percentage share of cost responsibility and revenue contribution by FHWA vehicle class and NCDOT's 5 vehicle class, respectively. Figure 6.3 shows the equity ratios for these two vehicle classification systems.

Table 6.1: Equity ratios for FHWA 13 vehicle class, 2014-2017.

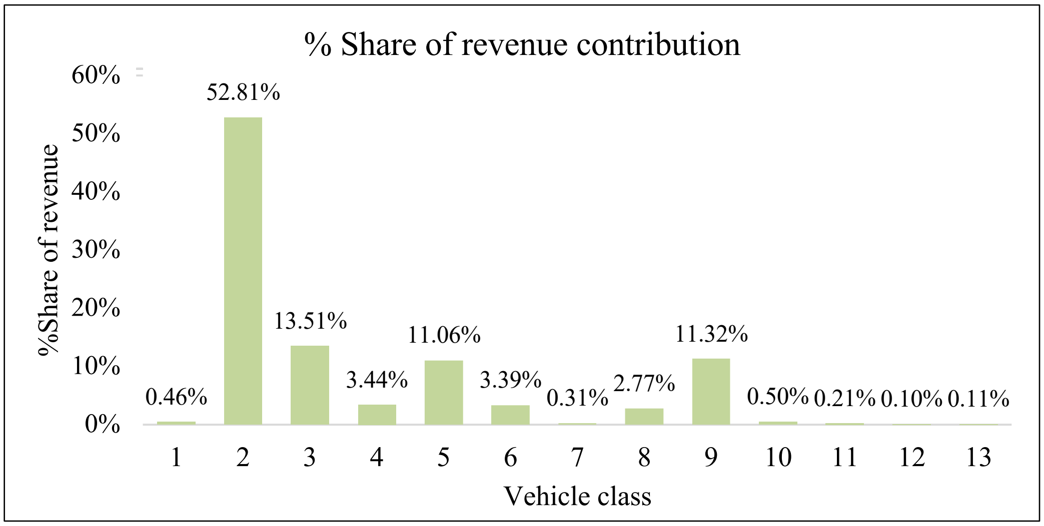
FHWA vehicle class		% Share of cost responsibility	% Share of revenue	Equity ratio
1	MC	0.35%	0.76%	1.30
2	Cars	41.93%	56.68%	1.26
3	2A4T	12.49%	13.56%	1.08
4	Bus	3.03%	3.14%	1.13
5	2ASU	6.23%	10.00%	1.78
6	3ASU	2.81%	3.10%	1.20
7	4ASU	0.49%	0.28%	0.63
8	4AST	5.27%	2.35%	0.53
9	5AST	23.13%	9.35%	0.49
10	6AST	2.33%	0.42%	0.22
11	5AMT	0.43%	0.18%	0.50
12	6AMT	0.23%	0.08%	0.42
13	7AMT	1.28%	0.09%	0.08

Table 6.2: Equity ratios for NCDOT's 5 vehicle class system, 2014-2017.

Vehicle class		**% Share of cost responsibility**	**% Share of revenue**	**Equity ratio**
MC	FHWA class 1	0.35%	0.46%	1.30
Cars	FHWA class 2	41.93%	52.81%	1.26
2A4T	FHWA class 3	12.49%	13.51%	1.08
SU Trucks	FHWA classes 4-7	12.57%	18.20%	1.45
MU Trucks	FHWA classes 8-13	32.66%	15.01%	0.46

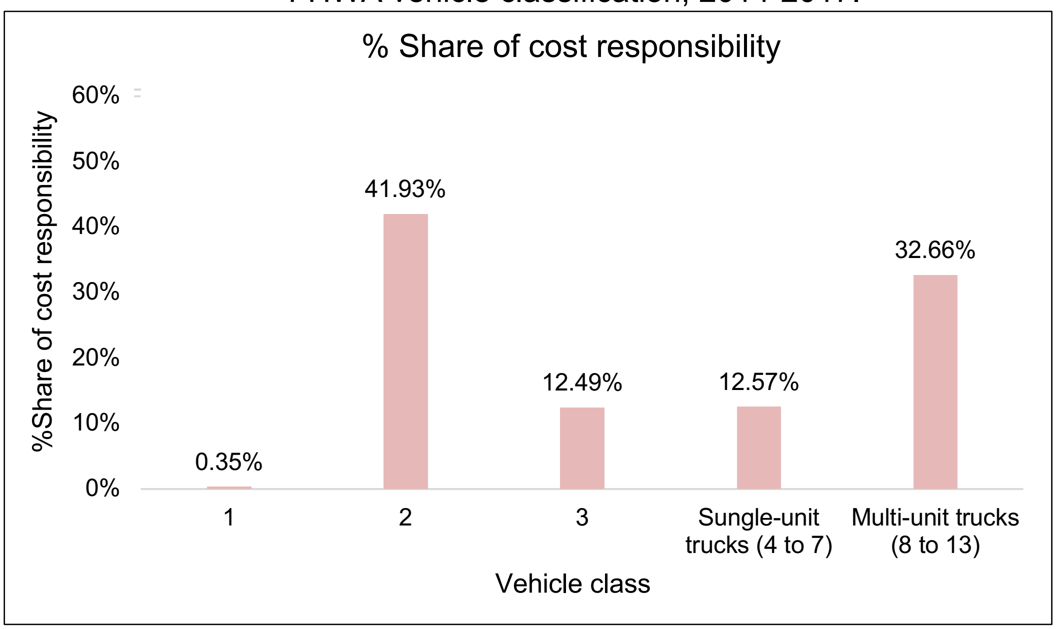


(a) Cost responsibility

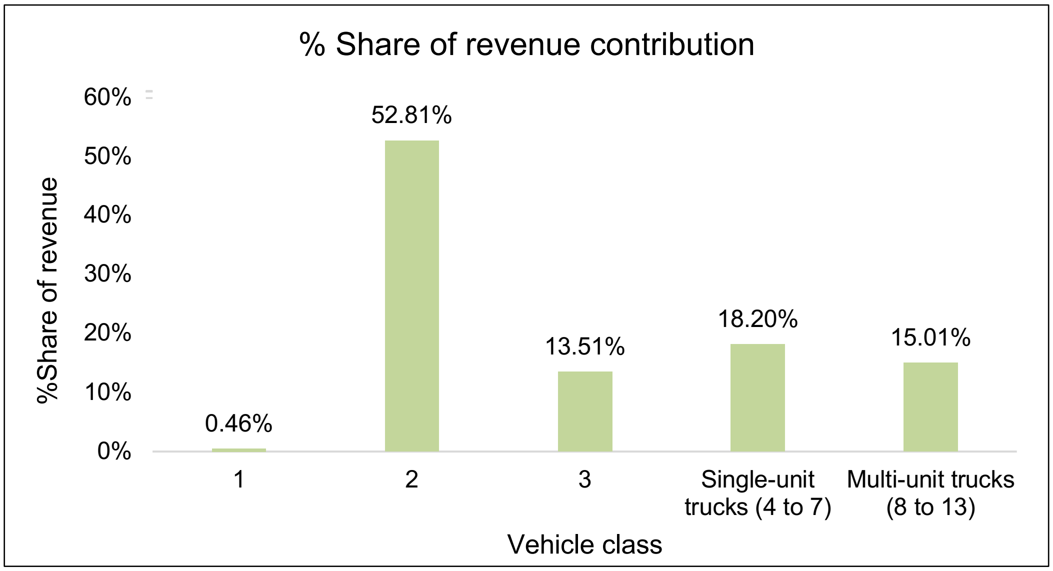


(b) Revenue contribution

Figure 6.1: Percentage share of cost responsibility and revenue contribution by FHWA vehicle classification, 2014-2017.

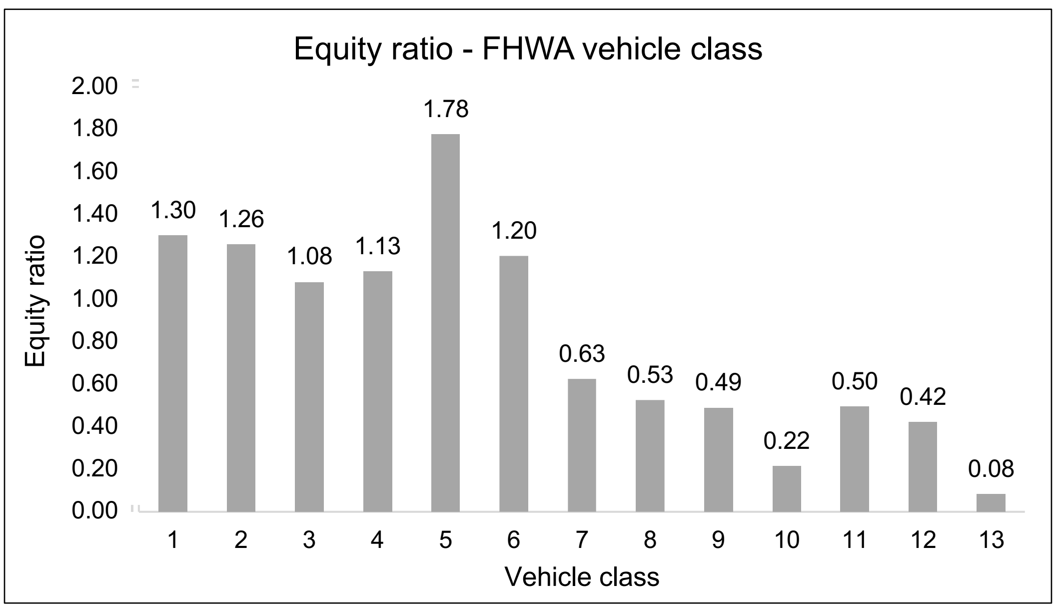


(a) Cost responsibility

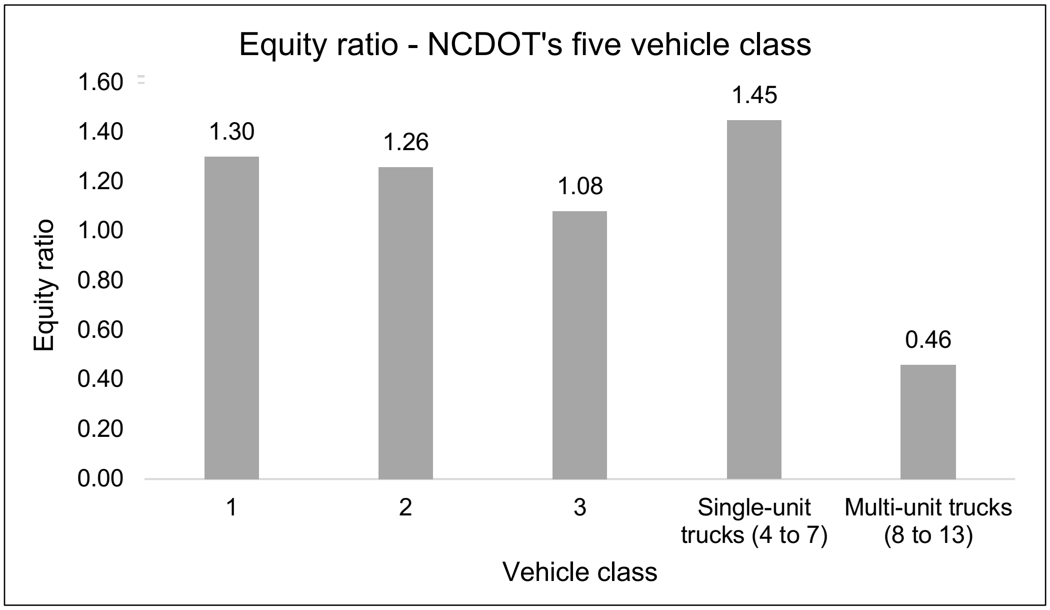


(b) Revenue contribution

Figure 6.2: Percentage share of cost responsibility and revenue contribution by NCDOT's 5 vehicle classes, 2014-2017.



(a) FHWA vehicle classification



(b) NCDOT's 5 vehicle classes

Figure 6.3: Equity ratio by vehicle class (a) FHWA vehicle classification, (b) NCDOT's 5 vehicle classes, 2014-2017.

From Table 6.1 and Figure 6.3(a), we see that FHWA vehicle classes 1-3 have an equity ratio greater than one. According to the results, motorcycle, passenger cars and four tire single unit vehicles overpaid 30%, 26%, and 8%, respectively. Similar trends are reported in HCAS studies from other states including Indiana, Minnesota, Nevada and Idaho (Balducci et al., 2010; Balducci et al., 2009; Gupta, 2012; Volovski et al., 2015). Equity ratios for passenger cars in these studies varied from 1.10 to 1.43.

Among the single-unit trucks, the only vehicles that underpaid were the FHWA class 7 trucks, at 37% of their cost responsibility. Other single-unit trucks have an equity ratio above 1.0, indicating that the amount of revenue collected from these vehicles is higher in proportion to their cost-responsible share. Class 5 vehicles, or single-unit trucks with two axle and six tires, have an equity ratio of 1.78, showing that class 5 vehicles overpaid by 78% during the study period. HCASs in other states have also reported equity ratios above one for several truck classes. For buses, Indiana reported equity ratios of 1.03 (Volovski et al., 2015). Minnesota's HCAS reported equity ratio of 1.44 and 1.19 for FHWA vehicle class 5 and class 6, respectively (Gupta, 2012, c). The unusually high equity ratio for class 5 vehicles can be attributed to the high percentage share of revenues to class 5 vehicles.

The multi-unit trucks in FHWA vehicle classes 8-13 have underpaid by 47% to 92% of their cost responsibility. Combined, the multi-unit trucks paid 54% less than their cost-responsible share (see Table 6.1and Figure 6.3(b)). FHWA class 13 vehicles have NC's lowest equity ratio, 0.08, meaning they underpaid by 92% from 2014 to 2017. Minnesota and Nevada reported that class 13 trucks underpaid by 68% and 72%, respectively (Balducci et al., 2009; Gupta, 2012).

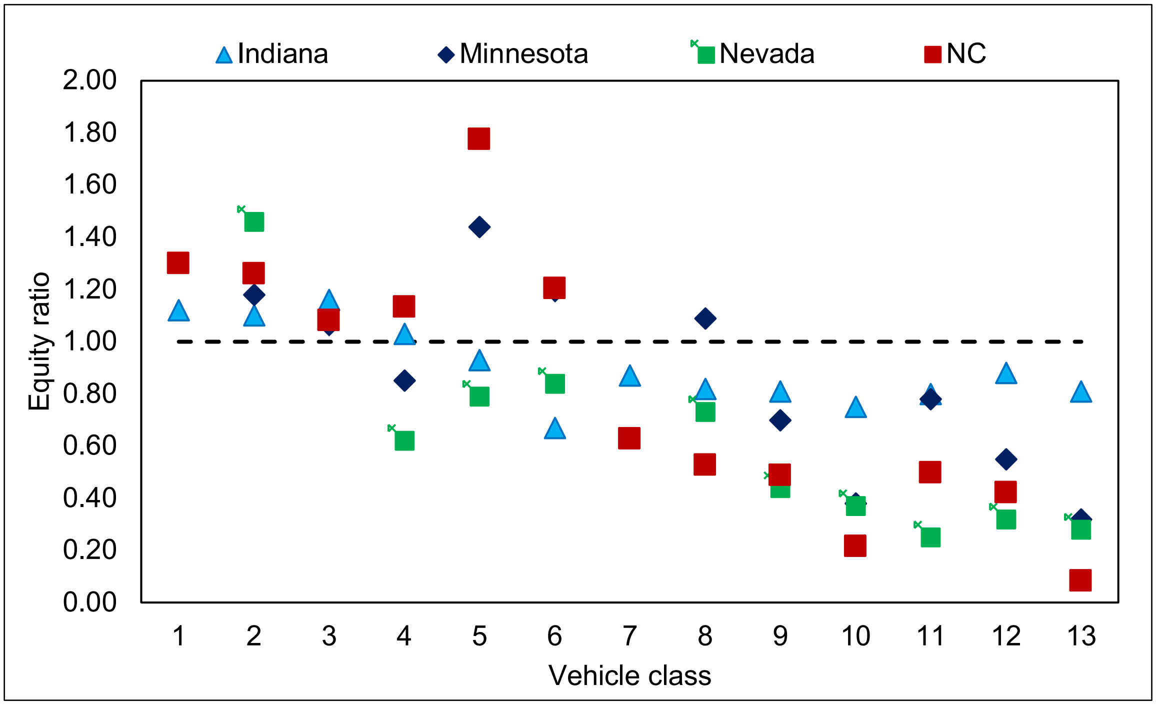


Figure 6.4: Equity ratios by FHWA vehicle classes across states.

Overall, the findings suggest that the lightweight vehicles are paying more than their fair share and the trucks (except vehicle class 4-6) are paying less than their fair share. Lightweight vehicles are subsidizing the cost responsibilities of the SU and MU trucks on North Carolina's highway system. For a perfect cost responsibility to revenue contribution, the equity ratio of any vehicles should be close to one, indicating that the vehicle is contributing to the revenue stream in accordance with its cost-responsible share. To ensure this happens moving forward, the NCDOT should explore new policy measures to collect more equitable revenues from the multi-unit trucks.

7 Alternative Funding Scenarios

Safe and efficient transportation infrastructure plays a vital role in the successful operation household activities, businesses, and the overall economy. Significant research effort has been devoted to the study of revenue generation mechanisms, their long-term effectiveness in raising adequate funds, and their acceptance by the public (Agrawal and Nixon, 2018; Dill and Weinstein, 2007; Dumortier et al., 2017; Norboge et al., 2019; Tonn et al., 2021). Multiple studies have emphasized the inability of the gas tax to sustain transportation revenue due to continuous improvements in vehicle fuel efficiency and the expected widespread adoption of electric vehicles (Dumortier et al., 2017; Duncan et al., 2020, 2017). In response, several states have conducted pilot studies and have explored altering and diversifying their revenue streams during the last decade (CalSTA, 2017; Mcmullen et al., 2010; Nordland et al., 2013; Thapa et al., 2020; WSTC, 2020).

This chapter investigates possible ways North Carolina could generate additional state revenues, either by increasing existing tax rates or introducing new revenue generation sources. Here, we estimate the policy changes that would need to be implemented in the main state revenue sources for NCDOT to generate an additional 10% to 30% total state revenue.

Table 7.1: Scenarios with increased revenue from state funding sources.

Year	Collected state revenue ($Millions)	Additional revenue ($Millions) from increasing the state revenue by		
		10%	20%	30%
2014	3,176.81	317.68	635.36	953.04
2015	3,323.75	332.37	664.75	997.12
2016	3,569.28	356.93	713.86	1,070.78
2017	3,621.04	362.10	724.21	1,086.31
Average	3,422.72	342.27	684.55	1,026.81

As seen in Table 7.1, increasing the state revenue by 10%, 20%, and 30% would have resulted in $342.27 million, $684.55 million, and $1,026.81 million additional annual revenue, respectively from the state revenue sources. We propose several scenarios where these additional revenues are attributed to existing revenue sources, i.e., state fuels tax, HUT, or motor vehicle fees. We also explore the efficacy of two new state revenue sources: introducing a dedicated sales tax for transportation use and implementing a mileage-based user fee (MBUF) system to replace the state fuels tax.

7.1 Increasing the State Motor Fuel Tax

Currently, the state fuel tax is 36.1 cents/gallon, which is 25% higher than the national average of 24.65 cents. NC has the 9th highest motor fuel tax rate in US; Pennsylvania has the highest per gallon fuel tax of 58.6 cents, followed by California (53.3 cents), Washington (52 cents), New Jersey (41.4 cents), New York (40.45 cents), Illinois (39.1 cents), Ohio (38.5 cents), and Maryland (36.89 cents) (WPR, 2021). Compared to its neighbors, NC has a substantially higher fuel tax. Georgia, Tennessee, South Carolina, and Virginia have a state fuel tax of 27.9, 27.4, 22.75, and 16.2 cents/gallon, respectively. However, even with a higher fuel tax rate, the revenue generated would fall short of increasing revenues sufficiently, in comparison with the changing travel behavior trends and the increasing adoption rate of fuel-efficient vehicles. From 2009 to 2019, the fuel efficiency for an average NC motorist increased by 2.2 miles per gallon (mpg) (Bert et al., 2020). In addition, from FY 2018 to FY 2019, the sales of electric vehicles (EVs) and hybrid vehicles increased by 69% and 4.4%, respectively (NC FIRST Commission, 2019). The combined effect of fuel efficiency improvements and increased adoption of EVs will continue to decrease the contribution of motor fuel tax.

We attribute all the additional revenues described in Table 7.1 to state fuel tax and estimate the tax rate that would have generated these additional revenues. Table 7.2 shows the additional revenues as percentage of collected state fuel revenues by year.

Table 7.2: Additional revenues ($Millions) as percentage of collected state fuel tax revenue ($Millions).

Revenue scenario		**10% increase in state revenue**		**20% increase in state revenue**		**30% increase in state revenue**	
Vehicle class	**Collected fuel tax revenue**	**Additional revenue**	**% of collected state fuel tax revenue**	**Additional revenue**	**% of collected state fuel tax revenue**	**Additional revenue**	**% of collected state fuel tax revenue**
2014	1,875.33	317.68	16.94%	635.36	33.88%	953.04	50.82%
2015	1,922.29	332.37	17.29%	664.75	34.58%	997.12	51.87%
2016	1,883.16	356.93	18.95%	713.86	37.91%	1,070.78	56.86%
2017	1,919.59	362.10	18.86%	724.21	37.73%	1,086.31	56.59%
Average	1,900.09	342.27	18.01%	684.55	36.03%	1,026.81	54.04%

As seen in Table 7.2, to increase the state revenue by 10%, NCDOT would have had to increase the revenue from state fuels tax by 18.01%. The research team has estimated the fuel tax rate that would have provided this additional amount from the state fuel tax. A long-run price elasticity for VMT of -0.241 (Hymel et al., 2010) is used to account for the reduction in VMT from non-trucks (vehicle class 1-3) as a response to the rising fuel tax. For trucks, we assumed zero elasticity because single-unit and combination truck travel in the US have near zero elasticity with respect to fuel cost (Winebrake et al., 2015a, 2015b). Table 7.3 shows the fuel tax required to collect the additional revenues.

Table 7.3: Changes in state fuels tax (cents per gallon) by year and funding scenario.

Year	Base Fuel tax	10% increase in state revenue		20% increase in state revenue		30% increase in state revenue	
		Required fuel tax	% Change	Required fuel tax	% Change	Required fuel tax	% Change
2014	37.00	37.35	0.94%	44.33	19.82%	52.07	40.72%
2015	36.75	38.15	3.81%	45.48	23.77%	53.67	46.04%
2016	34.50	36.73	6.47%	44.47	28.91%	53.27	54.42%
2017	34.30	36.62	6.76%	44.29	29.13%	53.00	54.51%
Average	35.59	37.19	4.49%	44.63	25.40%	53.00	48.90%

During the analysis period the state fuel tax was 37 center per gallon (CPG) in 2014, 36.75 CPG in 2015, 34.50 CPG in 2016, and 34.30 CPG in. The increased tax rate ranges from 36.62 cents per gallon to 53.67 cents per gallon. From Table 7.3, we see that to increase the state revenue by 10%, NCDOT would have had to raise the fuel tax by only 4.49%. We notice that the percentage increase in fuel tax rate is not equal to the percentage increase in total fuel tax revenue shown in Table 7.2. This is because fuel efficiency differs by vehicle type. In this analysis, we used the average fuel efficiency by vehicle type, shown in Table 5.7, to estimate the revenue from a modified fuel tax rate. For per mile travel, vehicles with higher fuel efficiency contribute less than the vehicle with lower fuel efficiency. Therefore, even with a lower percentage increase in per mile fuel tax, we found a higher increase in overall revenue from fuel tax. Table **7.4** shows the reduction in annual average VMT corresponding to the hypothetical increase in fuel tax rate. The highest estimated fuels tax of 53 cents per gallon is nearly equivalent to California's rate of 53.3 CPG, currently the second highest state fuel tax in the US. The estimated tax rates for a 10% and 20% increase in total state revenue are equivalent to current state fuel tax of 36.89 cents per gallon in Maryland (8th highest in the US) and 41.4 cents per gallon in New Jersey (4th highest in the US), respectively.

Table 7.4: Average annual VMT (billions), annual average revenue ($Millions) and fuel tax rate (cents per gallon) by revenue scenario, 2014-2017.

Revenue scenario	Total VMT	% Change in VMT*	Total state fuels tax revenue	State fuel tax rate
Base case	113.86	_	7,600.37	35.59
10% increase in state revenue	112.71	-1.01%	8,969.45	37.19
20% increase in state revenue	107.40	-5.67%	10,338.54	44.63
30% increase in state revenue	101.43	-10.92%	11,707.63	53.00

**Assumed price elasticity of VMT for non-trucks equal to -0.241 from Hymel et al.(2010)*

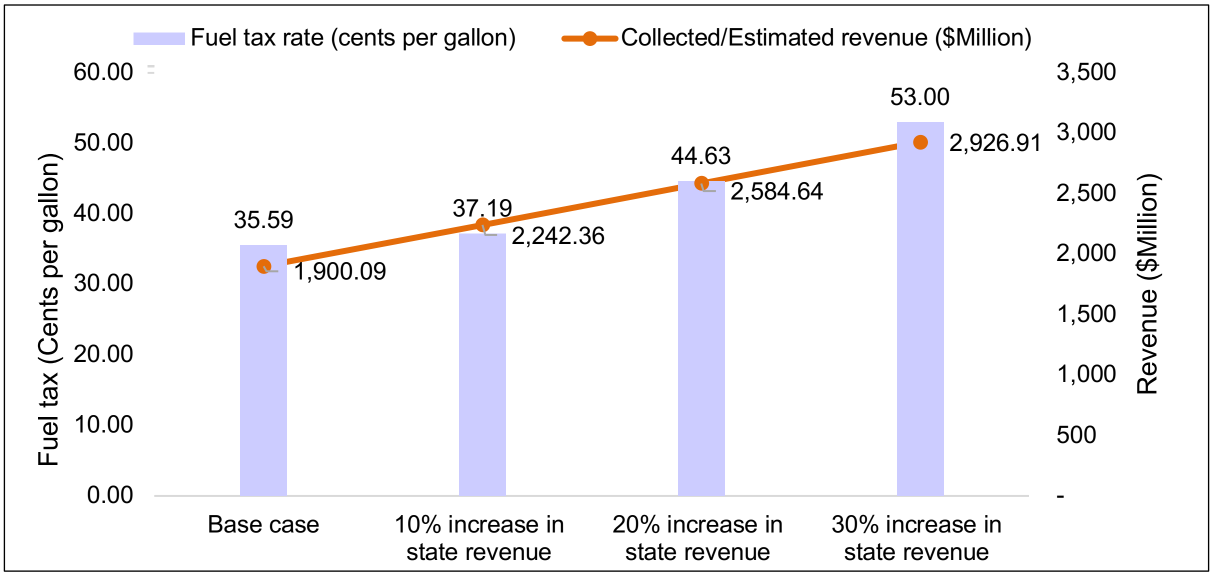


Figure 7.1: Average annual revenue from increased state fuel tax by revenue scenario, 2014-2017.

Table 7.5 presents the percentage change in user fees for the funding scenarios.

Table 7.5: Percentage change in user fees by vehicle class and revenue scenario resulting from additional state fuels tax, 2014-2017.

Revenue scenario:	**Base case**	**10% increase in state revenue**		**20% increase in state revenue**		**30% increase in state revenue**	
Fuel tax (CPG)	**35.59**	**37.19**		**44.63**		**53.00**	
Vehicle class	**Revenue contribu-tion ($/VMT)**	**Revenue contribu-tion ($/VMT)**	**% Increase in user fee**	**Revenue contribu-tion ($/VMT)**	**% Increase in user fee**	**Revenue contribu-tion ($/VMT)**	**% Increase in user fee**
1	0.0302	0.0315	4.26%	0.0345	13.95%	0.0379	25.41%
2	0.0283	0.0303	7.35%	0.0343	21.20%	0.0388	37.15%
3	0.0295	0.0323	9.32%	0.0371	25.83%	0.0427	44.66%
4	0.1982	0.2130	7.48%	0.2233	12.64%	0.2348	18.46%
5	0.1783	0.1930	8.28%	0.2033	14.02%	0.2148	20.49%
6	0.1979	0.2126	7.44%	0.2229	12.61%	0.2344	18.44%
7	0.2052	0.2199	7.21%	0.2302	12.20%	0.2417	17.82%
8	0.1664	0.1846	10.95%	0.1972	18.53%	0.2115	27.07%
9	0.1461	0.1642	12.44%	0.1769	21.08%	0.1911	30.81%
10	0.1462	0.1644	12.48%	0.1770	21.12%	0.1913	30.84%
11	0.1723	0.1905	10.58%	0.2031	17.91%	0.2173	26.16%
12	0.1724	0.1906	10.55%	0.2032	17.87%	0.2174	26.11%
13	0.1458	0.1643	12.71%	0.1769	21.37%	0.1911	31.12%
Average	0.0394	0.0428	8.74%	0.0481	22.20%	0.0543	37.97%

As seen from Table 7.5, class 1 vehicles would have experienced the lowest percentage increase in the per mile user fees. To increase the state revenue by 30%, passenger cars (class 2 vehicles) would have to pay an additional 0.96 cents per mile, 25.41% higher than the current base case. According to Federal Highway Statistics, from 2014 to 2017, a single passenger car traveled on average 11,303 miles (FHWA, 2019, 2018). With average fuel efficiency of 23.8 mpg (Table 5.7) and fuel tax of 35.59 cents per gallon (Table 7.3), a single passenger car paid $169 annually in fuel tax. To increase the collection of state revenue by 10%, 20%, and 30% a passenger car would have to pay $175, $199.95, and $226.89, respectively. In other words, average passenger car users would have to pay 3.55%, 18.31%, and 57.89% more, respectively, in annual fuel tax. Heavier vehicles, especially the multi-unit trucks would have to increase their share of user fees. For instance, to increase the collected state revenue by 30%, class 13 trucks would have to pay an additional 4.53 cents per mile, 31.12% higher than what they paid in the base case. Increasing the fuel tax would have penalized the vehicles with lower fuel economy more than the fuel-efficient vehicles. Table 7.6 presents the equity ratios by revenue scenario.

Table 7.6: Equity ratios by vehicle class and revenue scenario with increased fuels tax.

Vehicle class	**Base case (35.59 cents/gallon)**	**10% increase in state revenue (37.19 cents/gallon)**	**20% increase in state revenue (44.63 cents/gallon)**	**30% increase in state revenue (53.00 cents/gallon)**
1	1.30	1.25	1.21	1.17
2	1.26	1.24	1.24	1.24
3	1.08	1.09	1.11	1.12
4	1.13	1.13	1.11	1.09
5	1.78	1.79	1.76	1.74
6	1.20	1.20	1.18	1.16
7	0.63	0.62	0.61	0.60
8	0.53	0.54	0.54	0.54
9	0.49	0.51	0.51	0.52
10	0.22	0.23	0.23	0.23
11	0.50	0.51	0.51	0.51
12	0.42	0.43	0.43	0.43
13	0.08	0.09	0.09	0.09

Table 7.6 shows that increasing the fuel tax to 37.19 cents per gallon would have resulted in a higher percentage share of the revenue coming from less fuel-efficient vehicles. Specifically, it would have increased the equity ratios for class 3 and all the trucks. Higher fuel tax also affects the vehicles with higher annual VMT. Therefore, with increasing fuel tax, the revenue share of class 3 vehicles increases while the revenue share from single-unit trucks decreases. This leads to higher equity ratio for class 3 vehicles and reduced equity ratios for single-unit trucks.

7.2 Increasing the Highway Use Tax

HUT is responsible for approximately 20% of the state revenue and covers 16% of NCDOT's annual budget. From 2014 to 2017, the HUT on average contributed $714.60 million in revenue. NC has the lowest rate of HUT among the states that collect any form of sales tax on vehicle purchase, currently 3% of the vehicle purchase price. States with lower HUTs include Hawaii (4.5%), Maine (5.5%), and Wisconsin (5.6%). NC's neighboring states (Tennessee, South Carolina, Georgia, and Virginia) have HUT rates between 7% and 10%.

We attribute all the additional revenues described in Table 7.1 to HUT and estimate the HUT rate that would have generated the additional revenues from this sector. Table 7.7 shows the additional revenues as percentage of collected HUT revenues by year. Table 7.8 shows the HUT rate required to collect the additional revenues.

Table 7.7: Additional revenues ($Millions) as percentage of collected HUT revenue ($Millions).

Revenue scenario:		10% increase in state revenue		20% increase in state revenue		30% increase in state revenue	
Year	Collected HUT revenue	Additional revenue	% of collected HUT revenue	Additional revenue	% of collected HUT revenue	Additional revenue	% of collected HUT revenue
2014	620.14	317.68	51.23%	635.36	102.45%	953.04	153.68%
2015	692.35	332.37	48.01%	664.75	96.01%	997.12	144.02%
2016	760.60	356.93	46.93%	713.86	93.86%	1,070.78	140.78%
2017	785.31	362.10	46.11%	724.21	92.22%	1,086.31	138.33%
Average	714.60	342.27	48.07%	684.55	96.14%	1,026.81	144.20%

Table 7.8: Changes in HUT by year and revenue scenario.

Year	Base rate	10% increase in state revenue		20% increase in state revenue		30% increase in state revenue	
	HUT	HUT	% Change	HUT	% Change	HUT	% Change
2014	3.00%	4.54%	51.23%	6.07%	102.45%	7.61%	153.68%
2015	3.00%	4.44%	48.01%	5.88%	96.01%	7.32%	144.02%
2016	3.00%	4.41%	46.93%	5.82%	93.85%	7.22%	140.78%
2017	3.00%	4.38%	46.11%	5.77%	92.22%	7.15%	138.33%
2014-2017	3.00%	4.44%	47.90%	5.87%	95.79%	7.31%	143.69%

The estimated HUT rate for covering increase state revenues ranges from 4.38% to 7.61%. The highest rate (for a 30% increase in state revenue) is close to the HUT rates of Alaska and Nebraska (7.5%), and well below the highest rate of 11.5% in Louisiana and Oklahoma (Bert et al., 2020). From Table 7.8, we see that to increase the state revenue by 10%, NCDOT would have had to raise the HUT to 4.44%, an increase of 47.90% from the current rate. Figure 7.2 shows the estimated HUT rates required to collect the additional revenue.

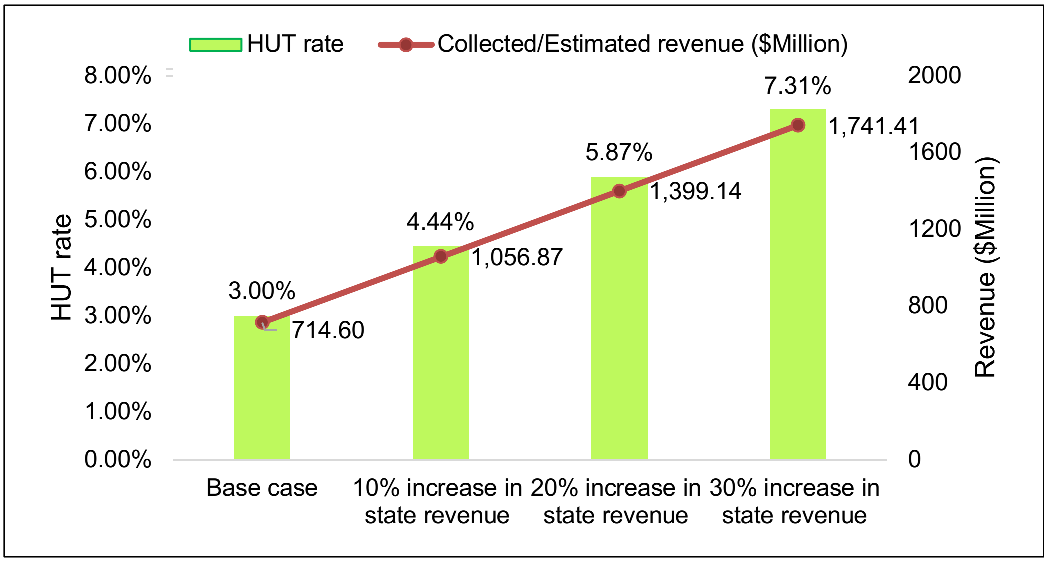


Figure 7.2: Average annual revenue from increased HUT rates by revenue scenario, 2014-2017.

Vehicle sales might decrease or individuals might choose to buy more affordable vehicles in response to increased HUT rate. It has been reported that an increase in vehicle property tax could lead to a reduction in vehicle capital (Craft and Schmidt, 2005). Another study estimated a decrease in greenhouse gas emissions from an increase in vehicle sales tax, which implies a reduction in VMT (Liu and Cirillo, 2015). Additional research is needed to better understand the short-term and long-term impacts of changes in vehicle sales tax and how they would affect revenue. For the analysis, we have ignored the possible changes in vehicle sales due to the rise in HUT rates. Table 7.9 shows the equity ratios by vehicle class and revenue scenario with increasing rate of HUT.

Table 7.9: Equity ratios by vehicle class and revenue scenario with increased HUT.

Vehicle class	Base case (HUT 3.00%)	10% increase in state revenue (HUT 4.44%)	20% increase in state revenue (HUT 5.87%)	30% increase in state revenue (HUT 7.31%)
1	1.30	1.29	1.28	1.28
2	1.26	1.24	1.23	1.22
3	1.08	1.02	0.97	0.93

4	1.13	1.18	1.21	1.24
5	1.78	1.86	1.94	2.00
6	1.20	1.25	1.29	1.32
7	0.63	0.65	0.67	0.68
8	0.53	0.54	0.56	0.57
9	0.49	0.51	0.53	0.55
10	0.22	0.23	0.23	0.24
11	0.50	0.51	0.52	0.53
12	0.42	0.43	0.44	0.45
13	0.08	0.09	0.09	0.09

The equity ratios for vehicles in classes 1-3 decrease because they have lower purchase price compared to single-unit and multi-unit trucks, while the rest of the equity ratios increase. Overall, an increase in HUT would have improved equity, but not substantially.

7.3 Increasing Motor Vehicle Fees

From 2014 to 2017, motor vehicle fees contributed on average $808.03 million to the annual revenue. Vehicle fees of NCDOT are not considered competitive compared to other states. The annual vehicle registration fee and driver's license fee for a private passenger car is $38.75 and $5.00/year, respectively, both below the national average of $54.69 and $6.70/year (NCDMV, 2020; WPR, 2020a, 2020b). Currently, Florida has the highest annual registration fee of $225 and Massachusetts has the highest driver's license fee of $21.25/year (WPR, 2020c). In addition, NC currently charges a $130 flat registration fee for EVs, whereas its neighbor, Georgia, charges $214 and $320 for non-commercial and commercial alternative fuel vehicles, respectively (NCDMV, 2020).

We attributed all the additional revenues described in Table 7.1 to motor vehicle fees. Table 7.10 shows the additional revenue as percentage of collected revenue from motor vehicle fees by year. We attributed the additional revenues to all motor vehicle fees using the percentage increase in Table 7.10. To have a better context, Table 7.11 shows the increased rate of some of the significant motor vehicle fees for passenger vehicles including vehicle registration fees, driver's license fee, and electric vehicle (EV) registration fee.

Table 7.10: Additional revenues ($Millions) as percentage of collected motor vehicle fees ($Millions).

Revenue scenario:		**10% increase in state revenue**		**20% increase in state revenue**		**30% increase in state revenue**	
Year	**Collected motor vehicle fees**	**Additional revenue**	**% of collected motor vehicle fees**	**Additional revenue**	**% of collected motor vehicle fees**	**Additional revenue**	**% of collected motor vehicle fees**

2014	681.34	317.68	46.6%	635.36	93.3%	953.04	139.9%
2015	709.11	332.37	46.9%	664.75	93.7%	997.12	140.6%
2016	925.53	356.93	38.6%	713.86	77.1%	1,070.78	115.7%
2017	916.14	362.10	39.5%	724.21	79.1%	1,086.31	118.6%
Average	808.03	342.27	42.36%	684.55	84.72%	1,026.81	127.08%

Table 7.11: Changes in annual motor vehicle fees for passenger vehicles by year and revenue scenario.

Year	**Type of fee**	**Current rate**	**10% increase in state revenue**	**20% increase in state revenue**	**30% increase in state revenue**
			Increased rate	**Increased rate**	**Increased rate**
2014	**Vehicle registration fee ($)**	38.75	56.82	74.88	92.95
2015			56.91	75.08	93.24
2016			53.69	68.64	83.58
2017			54.07	69.38	84.70
2014-2017			55.16	71.58	87.99
2014	**Driver's license fee ($)**	5.00	7.33	9.66	11.99
2015			7.34	9.69	12.03
2016			6.93	8.86	10.78
2017			6.98	8.95	10.93
2014-2017			7.12	9.24	11.35
2014	**Electric Vehicle registration fee ($)**	130.00	190.61	251.23	311.84
2015			190.93	251.87	312.80
2016			180.13	230.27	280.40
2017			181.38	232.77	284.15
2014-2017			185.07	240.13	295.20

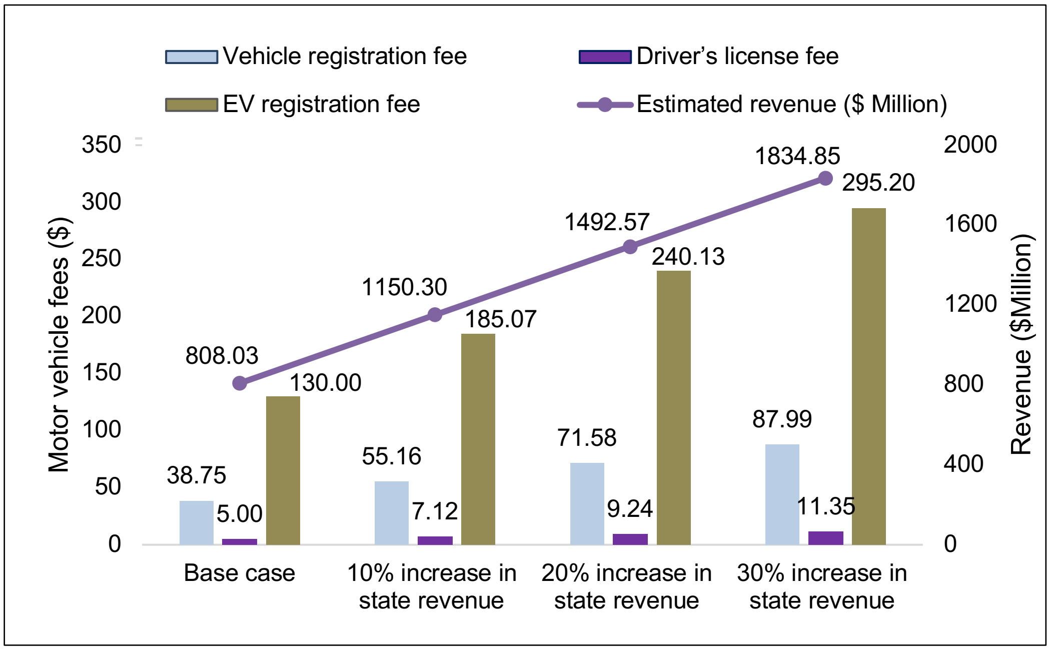


Figure 7.3: Average annual revenue ($Millions) from increased motor vehicle fees by revenue scenario, 2014-2017.

Estimates in Table 7.9 suggest that to ensure additional revenue equivalent to 30% of the collected state revenues on average, the current rate of vehicle registration fee would need to increase from $38.75 to $87.99 (127.1% increase). This is equivalent to the current vehicle registration fee in Connecticut ($88, 9th highest rate in the US) (WPR, 2020c). This would also increase the driver's license fee from $5 to $11.35, close to current rate in Nevada ($10.56, 5th highest in the US), as well as increase the EV registration fee from $130 to $295.20.Table 7.12 presents the equity ratios by vehicle class and revenue scenario with increased motor vehicle fees. We find that even a large increase in motor vehicle fees does not lead to substantial changes or improvements in the equity ratios.

Table 7.12: Equity ratios by vehicle class and revenue scenarios with increased rate of motor vehicle fees.

Vehicle class	Base case	10% increase in state revenue	20% increase in state revenue	30% increase in state revenue
% increase of motor vehicle fees		**42.36%**	**84.87%**	**127.08%**
1	1.30	1.47	1.61	1.73
2	1.26	1.25	1.25	1.24
3	1.08	1.02	0.97	0.92
4	1.13	1.22	1.29	1.35
5	1.78	1.86	1.93	1.99
6	1.20	1.29	1.37	1.44
7	0.63	0.67	0.70	0.73

8	0.53	0.54	0.55	0.56
9	0.49	0.48	0.48	0.47
10	0.22	0.21	0.21	0.21
11	0.50	0.50	0.51	0.52
12	0.42	0.43	0.43	0.44
13	0.08	0.08	0.08	0.08

7.4 Dedicated Sales Tax

At least 19 states in the US use sales tax revenue for funding transportation infrastructure. Among them, at least 12 states (including NC) collect local sales tax at the county level for transportation-related uses, while the rest dedicate a portion of the statewide sales tax to transportation. In NC, no sales tax revenue is allocated to roadway infrastructure. The state sales tax is 4.75%; 72 out the 100 counties collect an additional 2% sales tax. Three counties (Durham, Mecklenburg, and Wake) have imposed another 0.5% sales tax, which is directed towards funding their respective public transportation systems. North Carolina ranks 26th in the US in terms of total (state and local) sales tax rate. Tennessee, Louisiana, and Arizona have three of the highest total sales tax rates (approximately 9.5%), while California has the highest state sales tax rate (7.25%) (Cammenga, 2020).

In this subsection, the research team estimated the percentage of additional sales tax on all taxable sales and purchases that could have generated the additional revenues described in Table 7.1. We collected the total taxable sales and purchases in NC from 2014 to 2017 (Table 7.13) Next, we estimated the sales tax required to generate the additional revenues, which is the additional revenue divided by the total taxable sales and purchases of each year. Table 7.14 presents the estimated new state sales tax required to generate the additional revenues.

Table 7.13: Taxable sales and purchases ($Millions) by year.

Year	Taxable Sales and Purchases
2014	115,752.39
2015	123,968.14
2016	133,340.45
2017	142,773.68
Average	128,958.67

Table 7.14: Changes in state sales tax by year and revenue scenario.

Year	Base rate	10% increase in state revenue			20% increase in state revenue			30% increase in state revenue		
		Revenue from sales Tax ($Million)	Additional sales tax	New tax rate	Revenue from sales Tax ($Million)	Additional sales tax	New tax rate	Revenue from sales Tax ($Million)	Additional sales tax	New tax rate
2014	4.75%	317.68	0.27%	5.02%	635.36	0.55%	5.30%	953.04	0.82%	5.57%
2015		332.37	0.27%	5.02%	664.75	0.54%	5.29%	997.12	0.80%	5.55%
2016		356.93	0.27%	5.02%	713.86	0.54%	5.29%	1,070.78	0.80%	5.55%
2017		362.10	0.25%	5.00%	724.21	0.51%	5.26%	1,086.31	0.76%	5.51%
Average		342.27	0.27%	5.02%	684.54	0.53%	5.28%	1,026.82	0.80%	5.55%

As seen in Table 7.14, for the revenue scenarios examined herein, the average maximum state sales tax rate would have needed to be 5.55%. This is close to the current state sales tax of Nebraska 5.50%, which is the 29th highest state sales tax in the US (Cammenga, 2020).

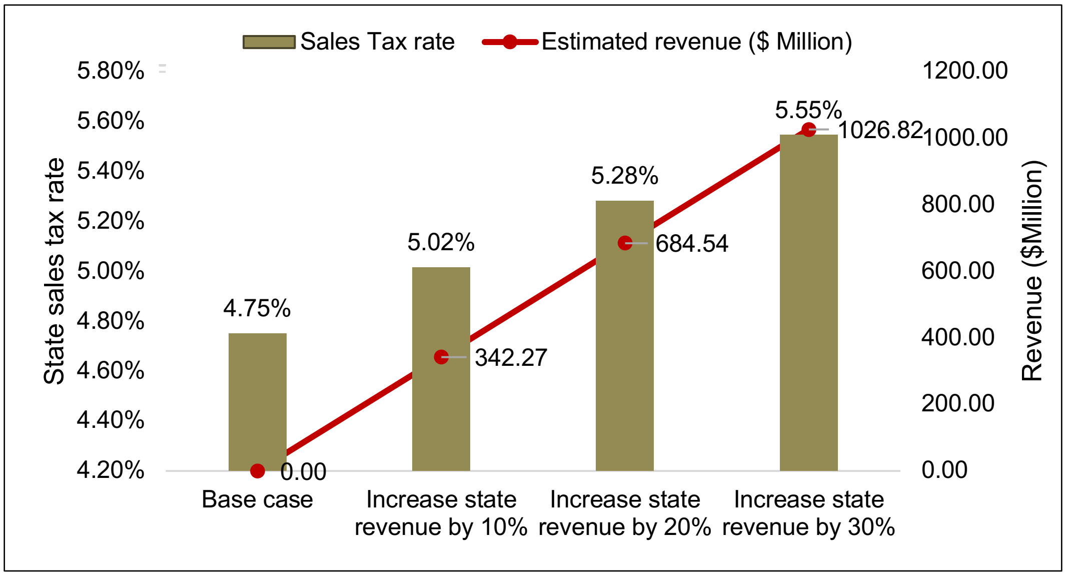


Figure 7.4: Average annual revenue from increased state sales tax by revenue scenario, 2014-2017.

We collected the annual per capita personal consumption expenditures (PCE) for NC from 2014 to 2017 (U.S. Bureau of Economic Analysis, 2020) and reported the impact of potentially increasing the state sales tax in $ per user.

Table 7.15: Increase in per capita expenditure ($) in sales tax by year and revenue scenario.

Year	Per capita PCE ($)	sales tax at existing rate of 4.75%	10% increase in state revenue		20% increase in state revenue		30% increase in state revenue	
			Sales tax ($)	% Change	Sales tax ($)	% Change	Sales tax ($)	% Change
2014	30,918	1,468.6	1,553.5	5.78%	1,638.3	11.56%	1,723.2	17.33%
2015	31,952	1,517.7	1,603.4	5.64%	1,689.1	11.29%	1,774.7	16.93%
2016	32,979	1,566.5	1,654.8	5.64%	1,743.1	11.27%	1,831.3	16.91%
2017	34,250	1,626.9	1,713.7	5.34%	1,800.6	10.68%	1,887.5	16.02%
Average	32,525	1,544.9	1,631.3	5.59%	1,717.6	11.18%	1,803.9	16.76%

Table 7.15 shows residents of NC, on average, made $32,525 in PCEs per year from 2014 to 2017. The average annual spending in sales tax was $1,544.90 during this period, based on the current sales tax rate of 4.75%. To collect revenue equivalent to 10-30% of the collected state revenue, the average individual taxpayer would have to spend $86.40-$259 more on state sales tax.

7.5 Mileage-based User Fee

The research team also explored the possibility of replacing the state fuels tax with a mileage-based user fee (MBUF) system. As an effort to diversify the transportation revenue structure, several states have tested and some have implemented MBUF systems (CalSTA, 2017; ODOT, 2020; WSTC, 2020). Eight states are currently planning or have completed MBUF pilot programs, while Oregon and Utah have fully operational, voluntary MBUF systems (ODOT, 2020). The rates being applied and/or tested in other states range from 1.8 cents/mile to 2.4 cents/mile for passenger vehicles.

We began by estimating the per mile fee needed to replace the existing state fuels tax to generate the same revenue collected from state fuels tax from 2014-2017. We have estimated a flat rate MBUF for FHWA vehicle class 2 (passenger cars) and class 3 (2-axle 4-tire vehicles). Higher fees are introduced for trucks. Higher rates for trucks are justifiable given the greater damage they cause to road and bridge infrastructure, as well as the environment compared to passenger vehicles (AASHTO, 1993b; Luskin and Walton, 2001; Vaidyanathan and Langer, 2011). Oregon has the only functioning MBUF program with different fee structures for trucks and passenger cars. The truck MBUF system in Oregon imposes a base fee of 6.2 cents/mile on trucks with gross weight over 26,000 lbs; the fee increases at a rate of 0.3 cents/mile for every 2,000 lbs up to 60,000 lbs, and 0.9 cents/mile for every 2,000 lbs up to 80,000 lbs (CBO, 2019). The highest rate for trucks can reach up to 28.8 cents/mile based on weight and axle configuration (CBO, 2019). For this case study, the starting rate of mileage-based fee for trucks (FHWA class 4-13) weighing over 26,000 lbs. has been selected to be 3.4 times the rate of the passenger cars, following the base rate for passenger cars and trucks in Oregon's MBUF system. From NCDOT's WIM data, we found the percentage of AADT for the trucks (FHWA class 4-13) recorded under different weight bins on interstate and US routes. We assumed that the VMT distribution will have the same weight distribution and estimated the truck revenues using Oregon's fee structure. We did not include motorcycles in the MBUF, as no state has either implemented or tested MBUF for this class. We assumed, for revenue calculation, that motorcycles will be charged by the state fuel tax. Table 7.16 presents the estimated MBUF for passenger vehicles and trucks.

Table 7.16: Estimated MBUF (cents per mile) for passenger vehicles and trucks by year and funding scenario.

Funding scenario	Replace existing fuels tax		10% increase in state revenue		20% increase in state revenue		30% increase in state revenue	
Year	**Fee for class 2-3 vehicle**	**Base fee for class 4-13 vehicle**	**Fee for class 2-3 vehicle**	**Base fee for class 4-13 vehicle**	**Fee for class 2-3 vehicle**	**Base fee for class 4-13 vehicle**	**Fee for class 2-3 vehicle**	**Base fee for class 4-13 vehicle**
2014	1.37	4.68	1.69	5.78	2.05	7.01	2.46	8.40
2015	1.35	4.63	1.68	5.76	2.05	7.02	2.48	8.48
2016	1.27	4.33	1.61	5.50	2.00	6.83	2.46	8.40
2017	1.25	4.29	1.59	5.44	1.98	6.75	2.43	8.31
2014-2017	1.31	4.48	1.64	5.62	2.02	6.90	2.46	8.40

The highest fee estimated in Table 7.16 is 2.46 cents/mile for class 2 and 3 vehicles, whereas the current highest rate suggested in the US is 2.4 cents/mile by the Washington State Transportation Commission to replace the current state fuels tax of 49.4 cents/gallon (WSTC, 2020).

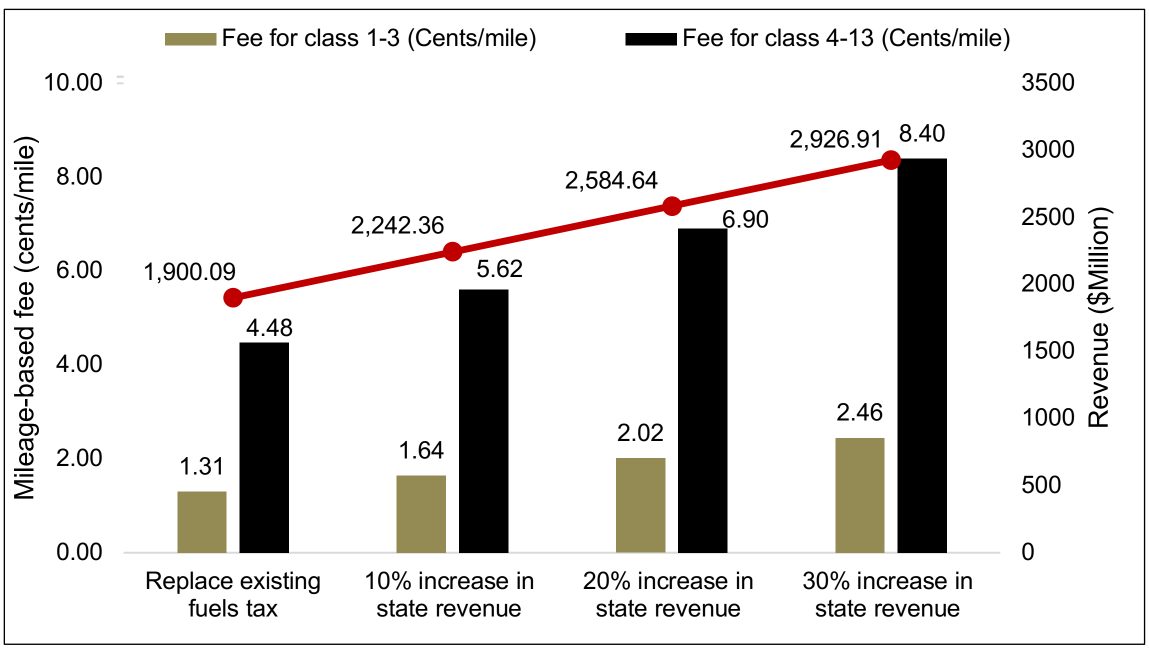


Figure 7.5: Average annual revenue from MBUF system by revenue scenario, 2014-2017.

Similar to increasing the state fuels tax, we have adopted a long-run price elasticity of -0.241 (Hymel et al., 2010) to adjust the VMT in response to the changes in cost. For class 2 and class 3 vehicles, the percentage change in per mile travel cost from fuel tax is estimated using their corresponding fuel efficiencies (Table 5.7). For instance, in 2014, class 2 vehicles paid 1.6 cents/mile (37 cents per gallon fuel tax divided by average fuel efficiency 23.2 mpg). With the MBUF in 30% increase of state tax revenue, class 3 vehicles would have to pay a 2.46 cents/mile fee. This would have increased their per mile cost by 42.02%, resulting in a decrease in VMT from passenger cars. A similar procedure is followed for class 3 vehicles. Conversely, the VMT increases for the scenarios where the per mile fee is lower than the per mile costs from fuels tax. For instance, in 2014, replacing the current state fuel tax with MBUF would have required 1.37 cents/mile fee, which is 14.10% and 36.68% lower than the per mile costs from fuel tax for class 2 and class 3 vehicles, respectively. Therefore, this would have increased the overall VMT. The results suggest that we could have had the same revenues that was collected from state fuel tax by replacing it with a lower equivalent rate of per mile fee. This is mainly due to selecting a higher fee structure for truck VMT. Although the VMT from class 2 and class 3 increases, excess travel at the same time contributes to the additional revenues from per mile fees. Table 7.17 presents the changes in total VMT and estimated collection of revenues from MBUF system for the funding scenarios.

Table 7.18 shows the percentage change in user fee by vehicle class and revenue scenario.

Table 7.17: Average annual VMT (billion), annual average revenues ($Millions) and MBUF (cents per mile) by revenue scenario, 2014-2017.

Revenue scenario	VMT	% Change	Estimated Revenue	Fee for class 2-3 vehicle	Base fee for class 4-13 vehicle
Base case	113.86	N.A.	N.A.	N.A.	N.A.
Replace existing fuels tax	118.16	3.77%	7600.37	1.31	4.48
Increase state revenue by 10%	112.83	-0.91%	8969.45	1.64	5.62
Increase state revenue by 20%	106.83	-6.17%	10338.54	2.02	6.90
Increase state revenue by 30%	99.83	-12.32%	11707.63	2.46	8.40

Table 7.18: Percentage change in user fee by vehicle class and revenue scenario resulting from implementing an MBUF system, 2014-2017.

	Base case	Replace existing fuels tax		10% increase in state revenue		20% increase in state revenue		30% increase in state revenue	
Vehicle class	**Revenue ($/VMT)**	**Revenue ($/VMT)**	**% Increase in user fee**	**Revenue ($/VMT)**	**% Increase in user fee**	**Revenue ($/VMT)**	**% Increase in user fee**	**Revenue ($/VMT)**	**% Increase in user fee**
1	0.0302	0.0308	1.77%	0.0309	2.31%	0.0311	2.99%	0.0314	3.89%
2	0.0283	0.0271	-3.94%	0.0312	10.51%	0.0359	27.13%	0.0416	47.09%
3	0.0295	0.0232	-21.27%	0.0271	-8.31%	0.0314	6.46%	0.0366	24.01%
4	0.1982	0.2152	8.57%	0.2228	12.40%	0.2313	16.70%	0.2413	21.73%
5	0.1783	0.1952	9.49%	0.2028	13.75%	0.2113	18.54%	0.2213	24.13%
6	0.1979	0.2148	8.53%	0.2224	12.37%	0.2309	16.68%	0.2409	21.72%
7	0.2052	0.2221	8.26%	0.2297	11.96%	0.2382	16.12%	0.2482	20.98%
8	0.1664	0.1749	5.09%	0.1825	9.65%	0.1910	14.79%	0.2010	20.78%
9	0.1461	0.1545	5.77%	0.1621	10.97%	0.1706	16.82%	0.1806	23.64%
10	0.1462	0.1547	5.82%	0.1623	11.01%	0.1708	16.86%	0.1808	23.68%
11	0.1723	0.1807	4.92%	0.1883	9.33%	0.1969	14.29%	0.2069	20.08%
12	0.1724	0.1808	4.89%	0.1884	9.30%	0.1969	14.26%	0.2069	20.04%
13	0.1458	0.1545	6.03%	0.1621	11.24%	0.1707	17.10%	0.1806	23.94%
All vehicles	0.0394	0.0379	-3.63%	0.0428	8.62%	0.0484	22.86%	0.0552	40.18%

For the total VMT and revenue, the per mile user fee decreases by 3.63% when the existing state fuels tax is replaced with MBUF. This is not surprising, because replacing the existing fuel tax resulted in an increase in total VMT (from class 2 and 3 vehicles) without affecting the total revenue. With state fuel tax, the per-mile cost for the vehicles is the per gallon fuel tax divided by their fuel efficiencies. For instance, during 2014-2017, with an average fuel tax of 35.59 cents per gallon, class 2, class 3, single-unit trucks, and multi-unit trucks were paying 1.49 cents/mile, 2.05 cents/mile, 4.89 cents/mile, 6.03 cents/mile, respectively, as fuel tax. Therefore, replacing the current fuels tax with the MBUF system would have reduced the revenue share from vehicles in class 2 and class 3. However, MBUF higher than the existing per mile fuel tax cost would have increased the revenue share from class 2 and class 3 vehicles. Increased fees for trucks would have generated a significant amount of additional revenue from trucks as more than 70% of the trucks operate with weights over 26,000 lbs. and thereby are charged at least 3.4 times the charge of passenger vehicles (class 1 and class 2). This would have increased the per mile revenue share from the trucks.

In the base case (traditional system of fuels tax-based revenues), the single-unit and multi-unit trucks were contributing about 8.41% and 10.51% of the total state fuels tax, respectively. However, replacing the fuels tax with mileage-based fee would have collected about 12% of the total revenues from the trucks (class 4-13). This is also reflected in the equity ratios for the vehicle classes. Table 7.19 shows the equity ratios by revenue scenario for an MBUF system. Replacing the current state fuels tax with an MBUF system increases the equity ratios for the trucks as their revenue share increases compared to the state fuel tax system. This reduces the revenue share from class 2-3 vehicles and results in a decrease in their equity ratio. With increasing rate of MBUF, the percentage of revenue shares from class 2-3 vehicles increases as they have significantly higher share of VMT. This in result increases the equity ratio for class 2-3 vehicles. Motorcycles are not charged with MBUF and assumed to pay the usual fuel tax. This reduces the percentage share of revenue contribution as well as the equity ratio for class 1 vehicles.

Table 7.19: Equity ratios by vehicle class and revenue scenarios with MBUF system.

Vehicle class	**Base case**	**Replace existing fuels tax**	**10% increase in state revenue**	**20% increase in state revenue**	**30% increase in state revenue**
MBUF for class 2-3 (cents/mile)	**–**	**1.31**	**1.64**	**2.02**	**2.46**
1	1.30	1.32	1.24	1.16	1.10
2	1.26	1.25	1.26	1.27	1.27
3	1.08	0.93	0.97	1.00	1.04
4	1.13	1.23	1.18	1.15	1.12
5	1.78	1.94	1.88	1.83	1.79
6	1.20	1.31	1.26	1.22	1.19
7	0.63	0.68	0.65	0.63	0.62
8	0.53	0.55	0.54	0.52	0.52
9	0.49	0.52	0.50	0.50	0.49
10	0.22	0.23	0.22	0.22	0.22
11	0.50	0.52	0.50	0.49	0.49
12	0.42	0.44	0.43	0.42	0.41
13	0.08	0.09	0.09	0.09	0.08

8 Transportation Revenue during the COVID-19 Pandemic

The steep reduction in motor vehicle travel during the COVID-19 pandemic plummeted fuel sales across the US. Between April and September 2020, the average monthly consumption of refined gasoline was 18.12 million gallons, which is 27% lower than the average monthly consumption during the same months in 2019 (EIA, 2020). State departments of transportation (DOTs) across the US suffered significant loss in terms of revenue generation during the pandemic. Collectively, the state DOTs were projected to suffer $16 billion in lost revenue in fiscal year (FY) 2020, and an additional $37 billion in lost revenue over the next five FYs (AASHTO, 2020). In North Carolina, during April 2020, monthly VMT dropped by approximately 42%, resulting in a 25.6% drop in the total state revenue for May 2020 (Tasaico, 2020a). From March to October 2020, NCDOT recorded 16.6 billion fewer VMT than forecasted (an 18.63% decrease). NCDOT experienced a $300 million revenue loss in FY 2020 and has projected an additional deficit of $370 million for the next FY (Miller, 2020).

This chapter focuses on the adverse impacts of the COVID-19 pandemic on NCDOT's revenue stream and explores the feasibility of various funding mechanisms to reduce those negative impacts.

8.1 Impacts of COVID-19

The COVID-19 pandemic has significantly impacted the statewide travel and NCDOT's revenue collection. Figure 8.1 shows the predicted and estimated statewide VMT for NC from March to October 2020.

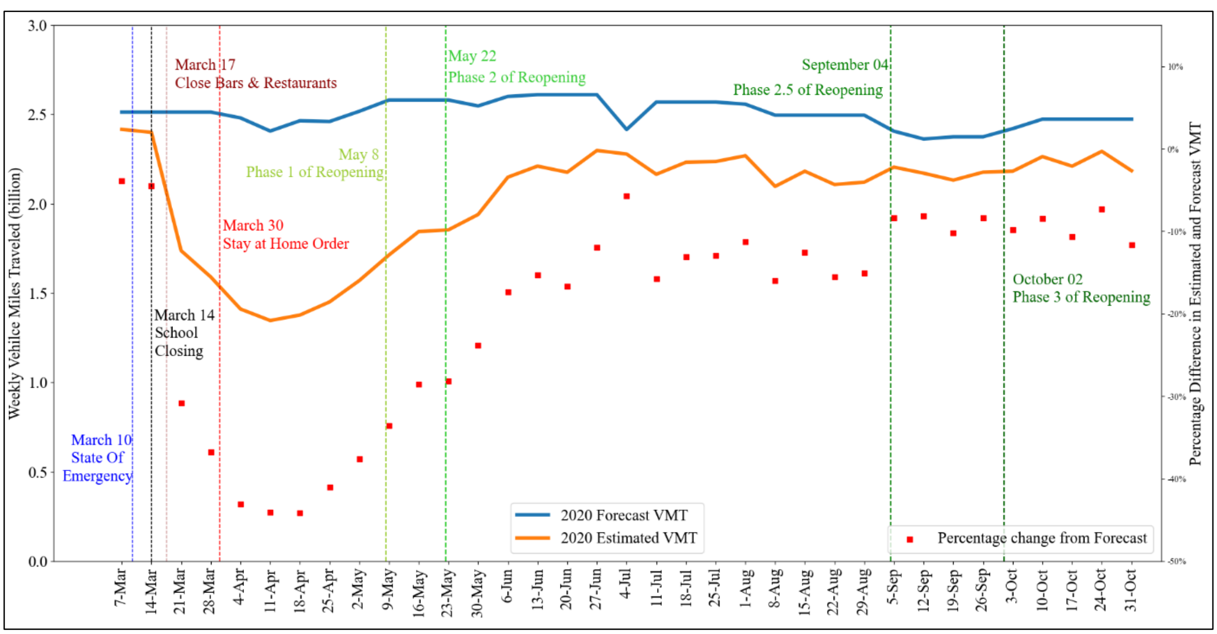
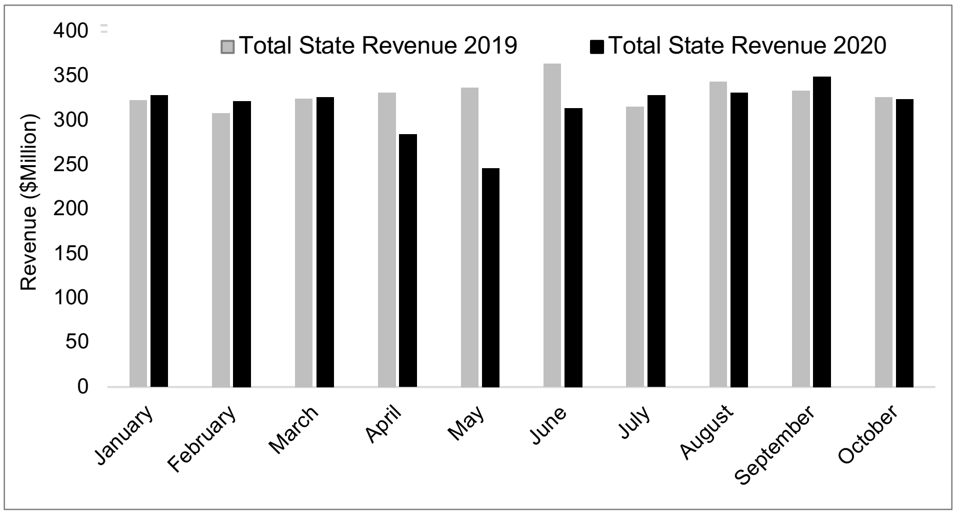


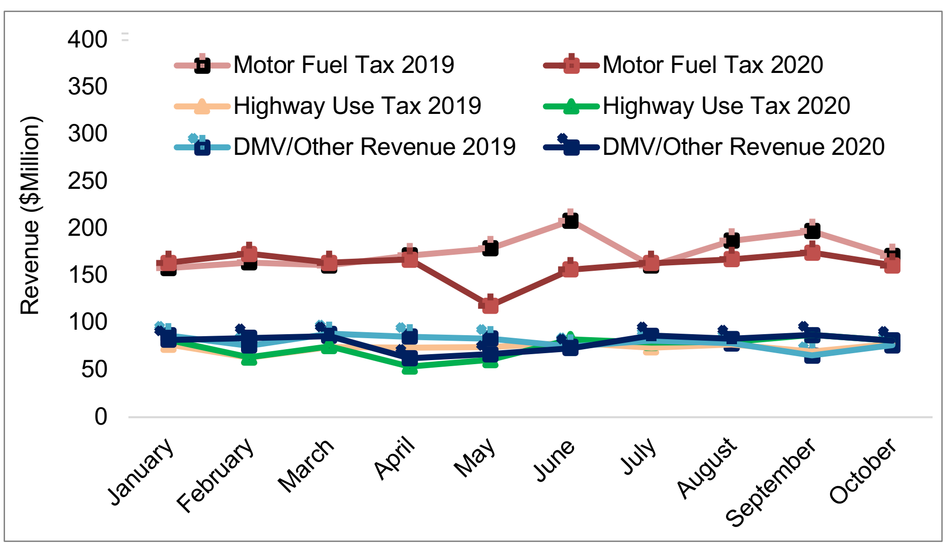
Figure 8.1: Impacts of COVID-19 on NC's Weekly VMT.

The estimated VMT are based on calibrated average daily traffic (ADT) data from 92 continuous count stations located across the state used to track the most recent travel trends. To report the changes in travel trends due to the COVID-19 pandemic, NCDOT compared the estimated daily VMT with the forecasted VMT for March-October of 2020 (Taylor, 2020).

NCDOT attributed 40.3%, 15.6%, and 17.2% of their total $5.3 billion budget for the FY 2020 to state fuel tax, HUT, and motor vehicle fees, respectively. Reduced travel impacted the revenue from state fuel tax, while economic hardship across the state affected the other major sources of revenue.



(a) Monthly Total State Revenue



(b) Monthly State Revenue by Source

Figure 8.2: Impacts of COVID-19 on NCDOT's State Revenue, January-October 2020.

As shown in Figure 8.2, NCDOT recorded its lowest monthly revenue, $246.6 million, in May 2020, one month after the lowest monthly VMT. (The effects of low travel rates are reflected in the revenue stream of the next month.) In FY 2020, the state's fuel consumption decreased by $446 million (a 7.6% reduction) compared to FY 2019. The revenue from motor fuels tax was directly related to the amount of travel and therefore was most adversely affected. The deadline for filing tax returns, including motor fuel tax returns, was extended to July 15, 2020. This shifted about $80 million in fuel revenue from April-June 2020 to July 2020 (NC FIRST Commission, 2020). The amounts shown in Figure 8.2 represent the adjusted revenues, where the $80 million fuel tax revenues from July 2020 was redistributed to April-June 2020 based on calculations provided by the NCDOT's revenue forecast team (B. Tasaico, 2020b). The DMV also closed some of their offices across the state considering the health and safety of the customers and employees and permitted a one-time, five-month extension for 27 different DMV credentials with expiration date between March 1 through July 31 (NCDMV, 2020a).

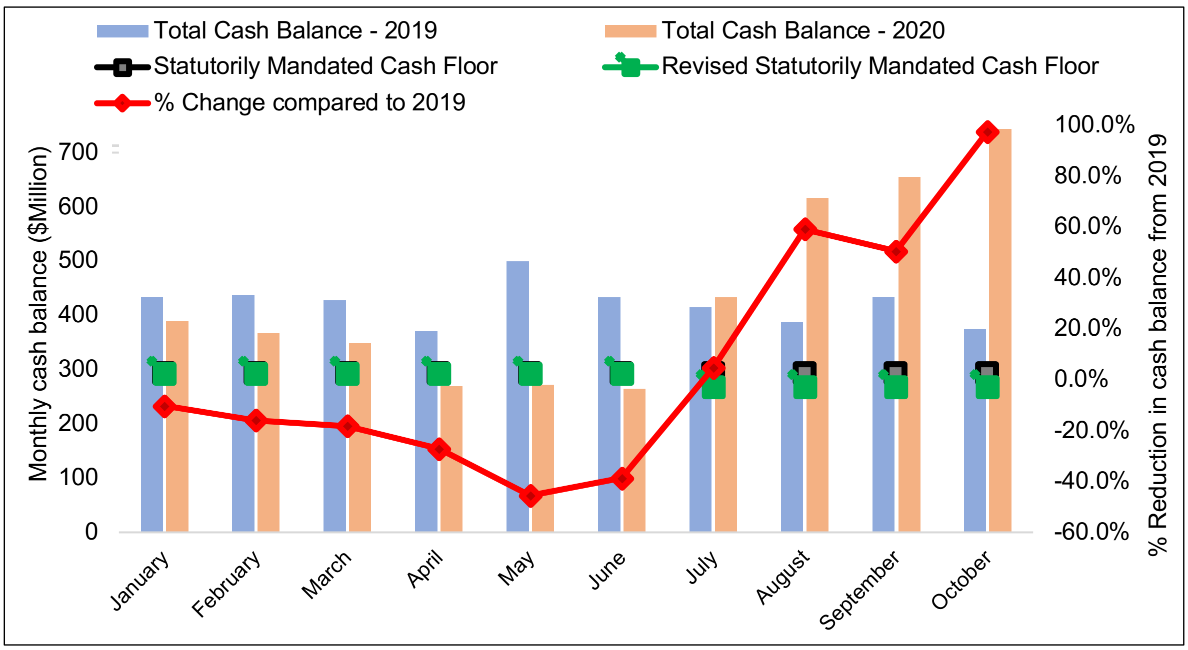


Figure 8.3: Impacts of COVID-19 on NCDOT's Cash Balance, January-October 2020.

During the first few months of the pandemic, NCODT's expenditure did not reduce as much as their revenue, as shown in Figure 8.3. This plummeted NCDOT's cash balance below the statutorily mandated cash floor of $293 million on April 2020 (SB-356, 2019). Falling below the statutory cash limit essentially prohibits NCDOT from entering into new contracts for transportation projects NCDOT (2020c). For this reason, on July 2020, the state set a new cash floor of $267.3 million (HB-77, 2020). The NCDOT drastically reduced their monthly expenditure between June and October 2020, which increased the cash balance in the Highway Fund and Highway Trust Fund after August 2020.

8.2 Efficacy of Existing and Alternative Funding Options

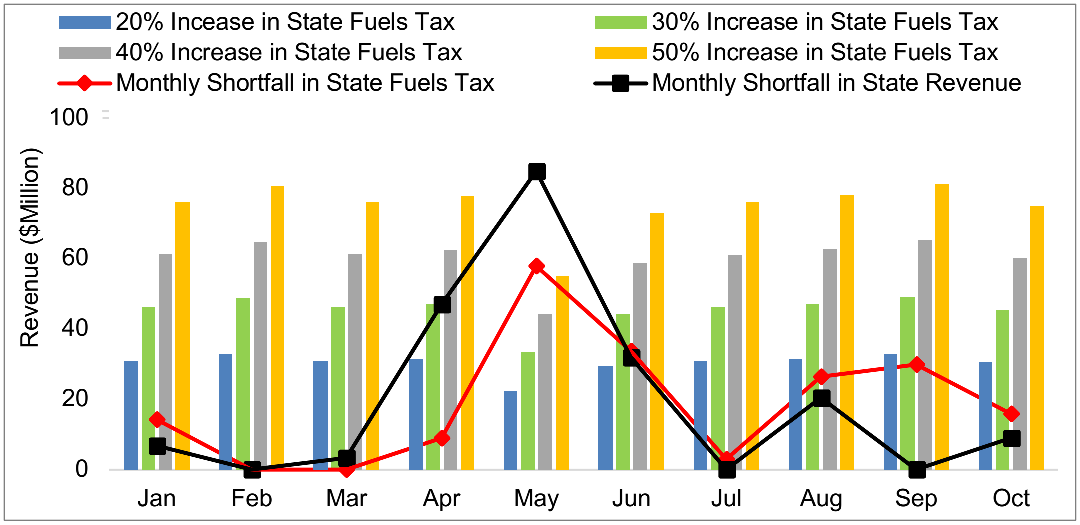
Our research team developed several scenarios and analyzed them in terms of their effectiveness to potentially provide adequate revenue to NCDOT during the COVID-19 pandemic. Basic setup of the proposed scenarios is based on the analysis in the previous chapter with some modification in the revenue generation structures (Table 8.1). In the previous chapter, we set a target additional revenue and estimated the required tax rates from the major state funding sources to meet that target. In the COVID-related analysis, we have increased the existing tax rates from the state fuel tax, HUT, and motor vehicle fees by a fixed amount and reported the additional revenues. We also analyzed scenarios where the increased fuel tax is replaced with MBUF system. Finally, in the last scenario we have assumed a percentage of state sales and use tax dedicated to transportation use and reported the potential additional revenues.

Table 8.1: State transportation revenue scenarios.

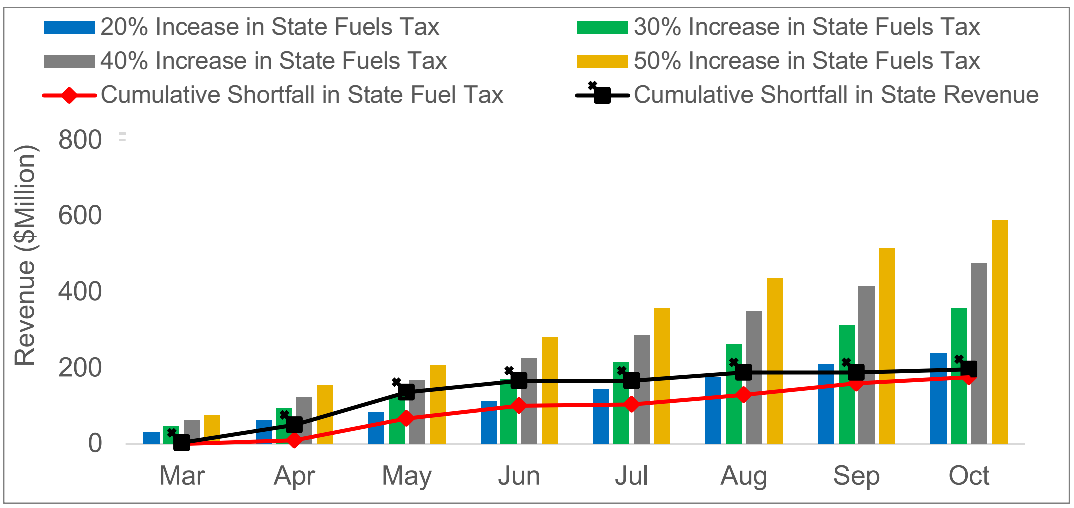
	Revenue source	**Current rate**	**Scenario**			
			1	**2**	**3**	**4**
A	Increase state motor fuels tax	36.1 cents/gallon	20% increase 43.32 cents/gallon	30% increase 46.93 cents/gallon	40% increase 50.54 cents/gallon	50% increase 54.15 cents/gallon
B	Increase motor vehicle fees		25% increase	50% increase	75% increase	100% increase
C	Increase highway use tax	3%	4%	6%	8%	10%
D	Replace state motor fuels tax with MBUF (base fee for trucks ≥26,000lbs)		1.81 cents/mile (6.21 cents/mile)	2.17 cents/mile (7.45 cents/mile)	2.35 cents/mile (8.07 cents/mile)	2.53 cents/mile (8.69 cents/mile)
E	Dedicate state sales tax to transportation use	4.75-7.25%	+0.25%	+0.5%	+0.75%	+1%

8.2.1 Increase in state motor fuels tax

As described in Table 8.1, we postulated an increase in the current state fuel tax during the analysis period by 10-50%. This raised the per gallon fuel tax from 36.1 cents to 54.15 cents, which is still lower than the highest state fuel tax in the US (Pennsylvania, at 57.6 cents per gallon). Figure 8.4 shows the additional revenue that could have been collected from an increase in state motor fuel tax. The additional revenue is the difference between the revenue that would have been collected for the higher tax rate based on each month's total VMT and the assumed fuel price elasticity, and the revenue actually collected.



(a) Monthly Additional Revenue



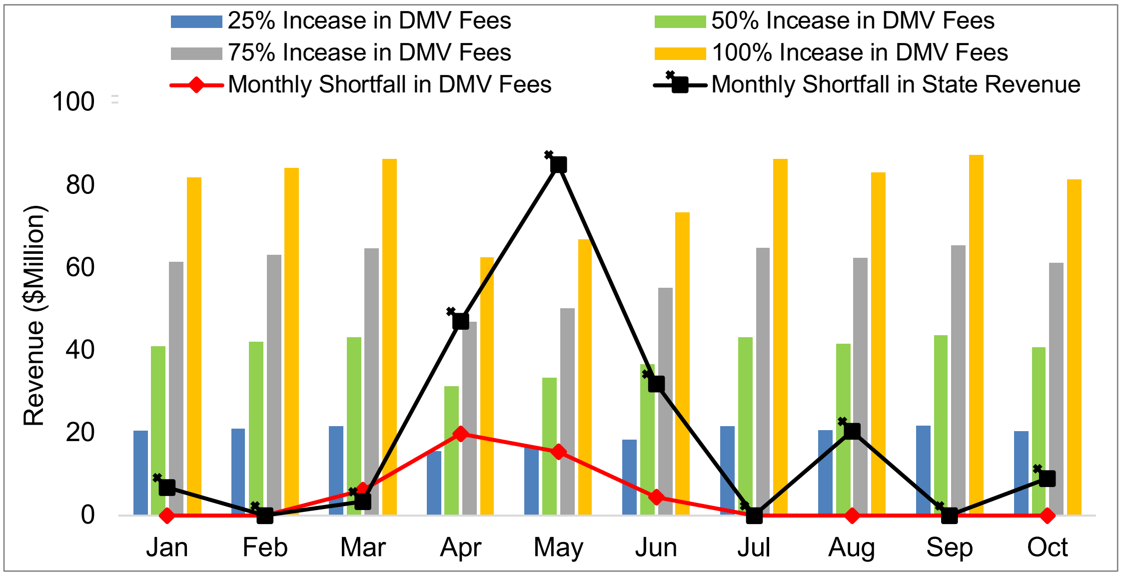
(b) Cumulative Additional Revenue since March 2020

Figure 8.4: Additional revenue from higher state motor fuel tax.

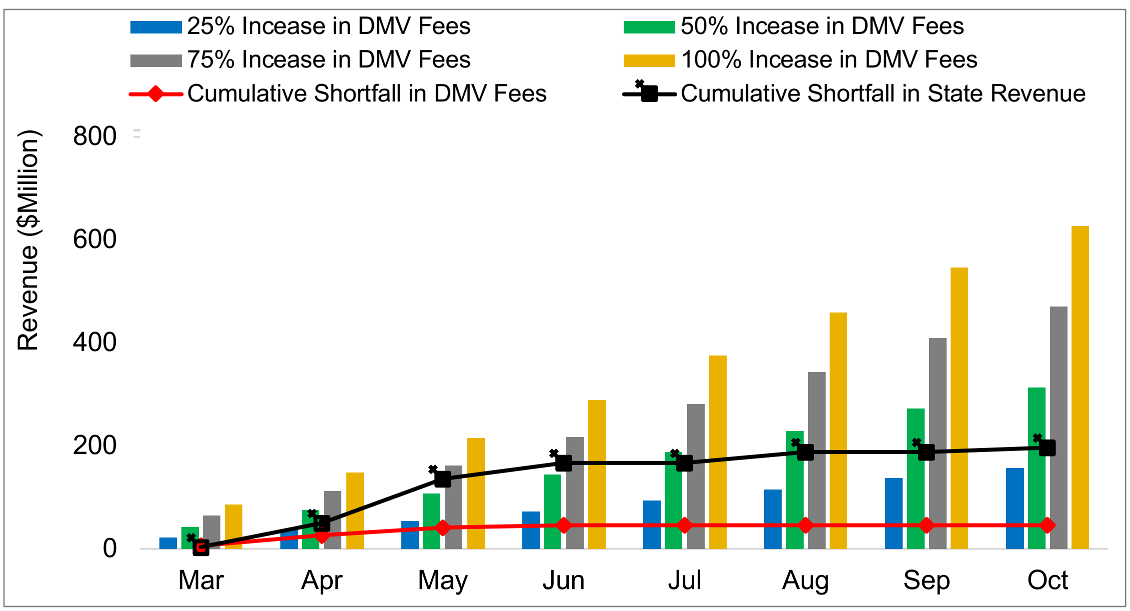
Figure 8.4(a) shows that even a 50% increase in the state fuel tax would not have provided sufficient additional revenue to offset the highest monthly shortfall in fuel tax revenue, which was $57.9 million for May 2020, let alone the highest monthly state revenue shortfall ($84.9 million).

8.2.2 Increase in motor vehicle fees

In scenario B, we increased the current motor vehicle fees by 25-100%. The highest increase corresponds $77.50 annual registration fee for passenger cars, which is close to the 12th highest fee in the US ($76 in Virginia) (WPR, 2020c). A 100% increase in DMV fees corresponds to a $10/year driver's license fee for passenger cars, equivalent to the current rate in New Hampshire (7th highest in the US) (WPR, 2020a).



(a) Monthly Additional Revenue



(b) Cumulative Additional Revenue since March 2020

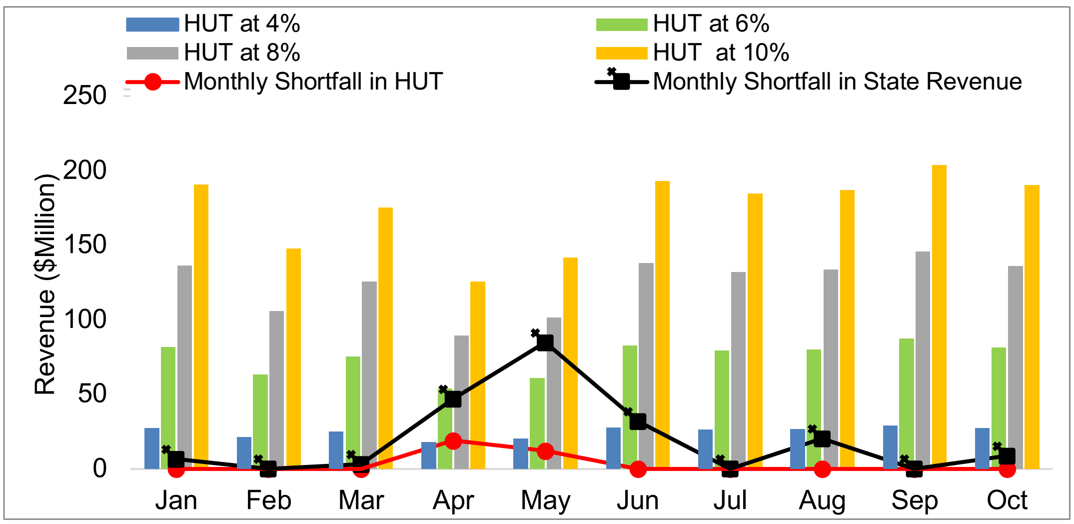
Figure 8.5: Additional Revenue due to Higher Motor Vehicle Fees.

Figure 8.5(a) shows the shortfall in motor vehicle fee revenue was mainly observed during the months of April and May 2020, when several of the DMV offices throughout NC were closed and extensions were provided for expiring licenses and registrations. Covering the monthly shortfall of revenue from this source would have required a more than 25%

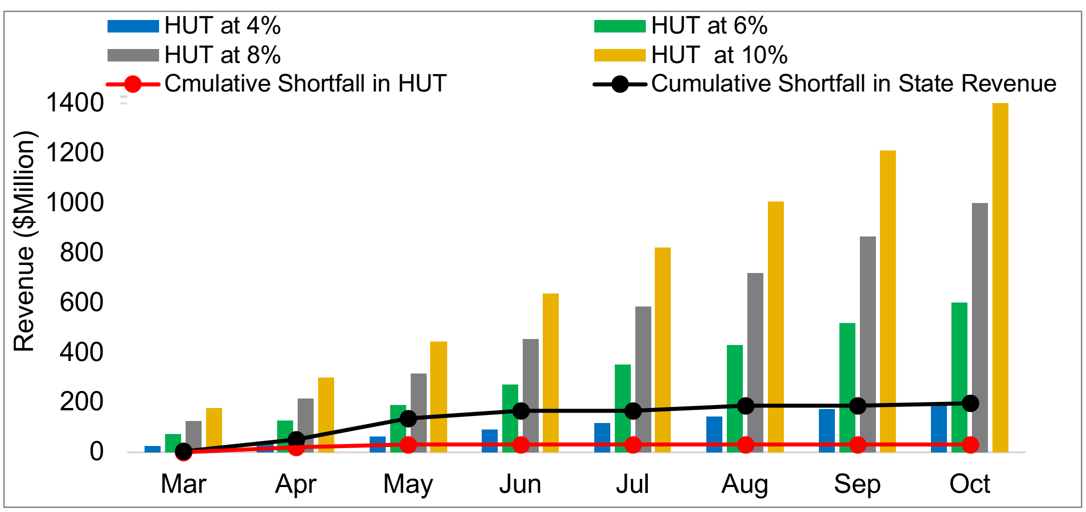
increase in fee charges. On the other hand, the monthly shortfall in state revenue is too high to be covered even with an 100% increase in charges for motor vehicle fees.

8.2.3 Increase in HUT

The third scenario involves incremental changes to the HUT rate. The highest proposed HUT rate (10%) is still within reason (the highest rate in the US is 11.5% in Oklahoma and Louisiana) and equal to the rate implemented by one of NC's neighboring states (Tennessee) (Bert et al., 2020). Figure 8.6(a) shows that the highest monthly loss in HUT revenue ($19.2 million) was recorded in April 2020, reflecting a more than 25% decrease for that month. Implementing a HUT rate close to 8% or 10% has significant potential to cover the monthly revenue gap.



(a) Monthly Additional Revenue

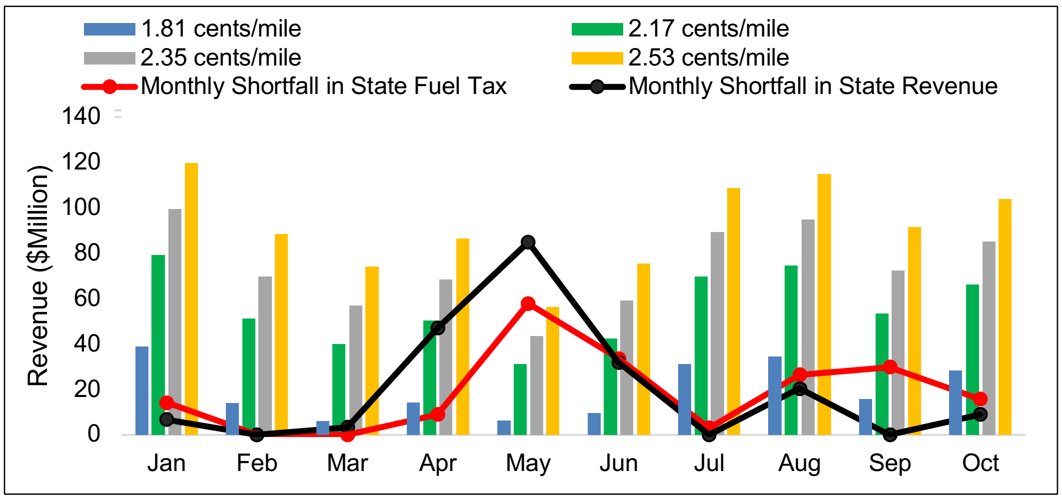


(b) Cumulative Additional Revenue since March 2020

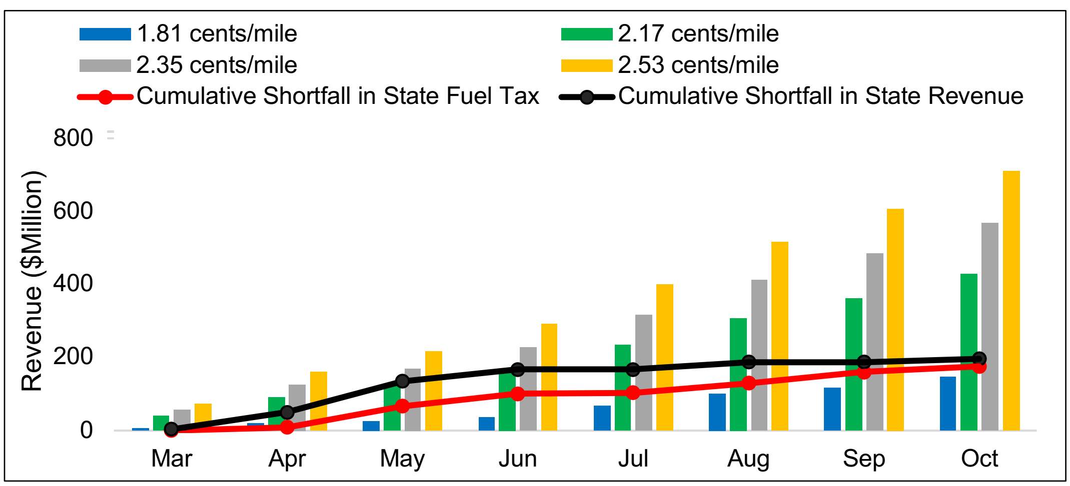
Figure 8.6: Additional revenue from higher highway use tax.

8.2.4 Mileage-based user fee

Scenario D examines the effectiveness of a MBUF system, beginning with a charge of 1.81 cents/mile, which would replace the fuels tax revenue, assuming an average fuel efficiency of 20 miles/gallon. This charge is similar to the charges tested in California and currently implemented in Oregon for passenger vehicles (1.8 cents/mile) (CalSTA, 2017; ODOT, 2020). The highest fee we tested is 2.53 cents/mile, which is higher than the current highest rate suggested by the Washington State Transportation Commission (2.4 cents/mile) to replace the current state fuel tax of 49.4 cents/gallon (WSTC, 2020). As explained in section 7.5, higher fees are introduced for trucks following the pricing structure for trucks in Oregon. To account for the changes in per mile travel cost, we have adopted a short-run price elasticity for VMT of -0.047 for passenger vehicles (Hymel et al., 2010).



(a) Monthly Additional Revenue



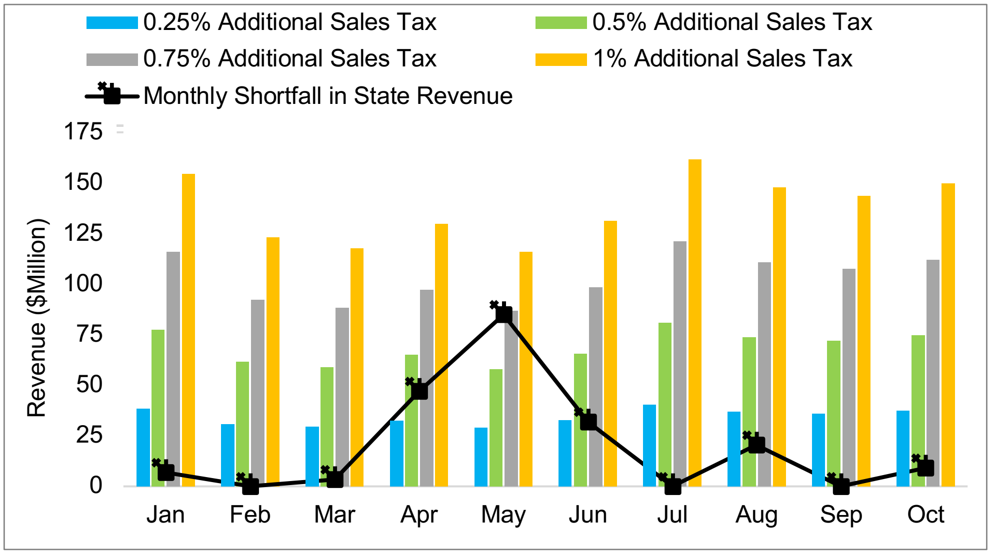
(b) Cumulative Additional Revenue since March 2020

Figure 8.7: Additional revenue (compared to state motor fuel tax) from mileage-based user fees.

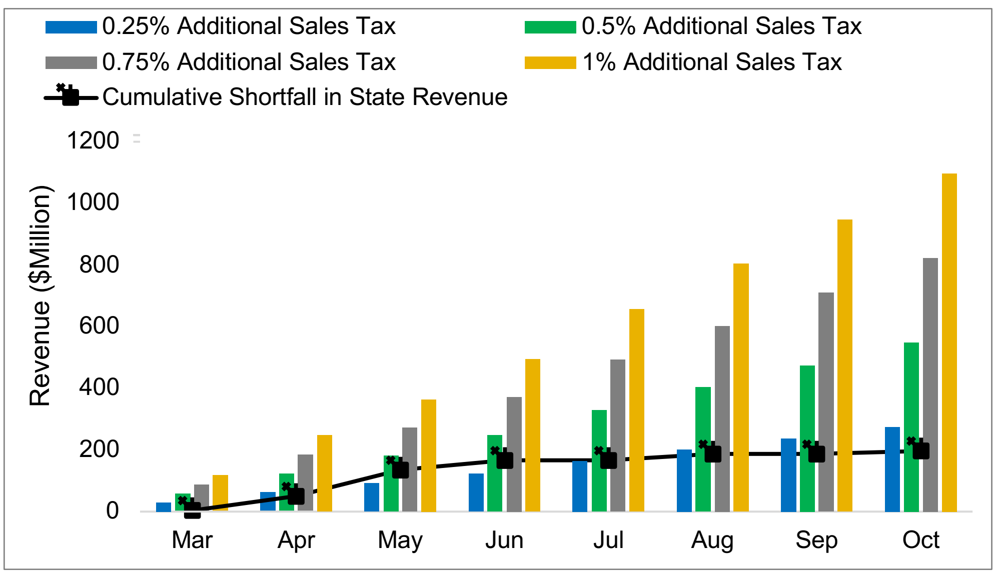
Figure 8.7(a) shows the difference between the monthly revenue from a MBUF system and the revenue from the current state fuel tax. The results indicate that one of the higher per-mile charges assumed could have closed the monthly shortfall in fuels tax revenue. This would require implementing a 2.53 cents/mile fee for passenger vehicles and fees that range from 8.65 cents/mile to 22.75 cents/mile for trucks. However, a MBUF system would not have been sufficient to cover the monthly shortfall in total state revenue due to its high reliance on the amount of travel. The VMT charges discussed in this section do not include the administrative and operational costs of an MBUF system, which have been estimated to be 10-13% of the total revenue collection (Bert et al., 2020; CBO, 2019; Kirk and Levinson, 2016).

8.2.5 Dedicated sales tax

Scenario E suggests an additional sales tax ranging from 0.25% to 1% to be collected as general transportation revenue. The highest proposed increment of 1% corresponds to a total statewide sales tax of 5.75%, which is close to the state sales tax of 6% in Michigan (17th highest in the US) (Cammenga, 2020). Figure 8.8 presents the revenue generated by a 0.25%-1% state sales tax allocated to transportation. Our results indicate that implementing a 0.75% additional sales tax could have generated sufficient revenue to cover the highest monthly shortfall in the total state transportation revenue.



(a) Monthly Additional Revenue



(b) Cumulative Additional Revenue since March 2020

Figure 8.8: Additional revenue form dedicating state sales and use tax for transportation use.

8.3 Conclusion

Among the three existing revenue sources in NC, the highway use tax is the least susceptible to travel fluctuations and is found to have the highest potential to generate sufficient revenue. Because the highway use tax constitutes a one-time cost to vehicle owners, raising the current tax rate is expected to face less public opposition than increasing the gas tax or the annual registration and license fees. NC has one of the lowest tax rates in the US, and this policy recommendation would be more applicable to states with a tax rate less than 8% or states that currently do not charge a tax on vehicle sales. Replacing the state fuel tax with mileage-based fees may be an appropriate long-term solution for state DOTs but would not be an optimal revenue mechanism during a pandemic. Instituting an additional sales tax dedicated to general transportation use provides promising results, even for tax rates that are lower than what is currently implemented in some states. We find that by imposing an additional 0.75% sales tax, NC could have avoided the monthly shortfall in transportation revenue. A dedicated sales tax for transportation has been suggested as a suitable long-term solution by previous studies (Bert et al., 2020). Our study demonstrates that it could also serve as an appropriate short-term solution in the context of a pandemic. Overall, the state sales tax revenue is not dependent on the amount of travel and is considered a stable source of revenue during an economic recession because it is not severely affected by fluctuations in the state GDP (Anderson and Shimul, 2018).

9 Appendix

9.1 VMT Split Factors

Table 9.1: VMT split factors (Source: FHWA, 1997).

FHWA vehicle	HCAS Vehicle Class (20) to Split to	Splits (%) By Highway System											
		Rural						Urban					
		Int	OPA	MA	MajC	MnC	Loc	Int	OFE	OPA	MA	Coll	Loc
8	CS3	37.90%	28.06%	53.65%	53.60%	37.71%	37.80%	37.74%	34.88%	31.26%	47.57%	47.69%	38.09%
	CS4	61.57%	71.68%	45.42%	45.38%	61.69%	61.83%	61.73%	64.36%	68.27%	51.93%	52.07%	61.40%
	CT4	0.53%	0.26%	0.93%	1.02%	0.61%	0.37%	0.53%	0.76%	0.47%	0.50%	0.23%	0.51%
	Total	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
9	3S2	87.20%	90.82%	84.75%	84.75%	88.49%	88.49%	86.84%	86.74%	87.91%	73.70%	73.70%	85.76%
	CS5	7.16%	7.06%	7.61%	7.61%	7.27%	7.27%	7.13%	4.45%	7.53%	8.39%	8.39%	6.95%
	CT5	5.63%	2.12%	7.65%	7.65%	4.24%	4.24%	6.03%	8.80%	4.56%	17.91%	17.91%	7.28%
	Total	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
10	CS6	58.08%	62.93%	60.91%	60.91%	62.10%	62.10%	59.56%	62.65%	62.96%	62.61%	62.61%	62.86%
	CS7+	33.95%	35.65%	34.51%	34.51%	35.19%	35.19%	34.41%	36.63%	36.82%	36.61%	36.61%	36.76%
	CT6+	7.97%	1.42%	4.58%	4.58%	2.71%	2.71%	6.03%	0.72%	0.22%	0.78%	0.78%	0.38%
	Total	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
13	DS7	26.84%	27.68%	27.68%	27.68%	27.68%	27.67%	26.63%	27.48%	27.48%	27.48%	27.48%	27.48%
	DS8	56.73%	59.45%	59.45%	59.45%	59.45%	59.46%	57.06%	59.40%	59.40%	59.40%	59.40%	59.40%
	TS	16.44%	12.87%	12.87%	12.87%	12.87%	12.87%	16.31%	13.12%	13.12%	13.12%	13.12%	13.12%
	Total *	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%

9.2 Weigh-in-Motion Data

The latest WIM data from NCDOT included observations from 35 stations situated on different highway routes. Gross vehicle weight (GVW) of truck traffic (FHWA class 4 to class 13 vehicles) were recorded on 11 interstates, 22 US routes, 1 NC route, and 1 secondary route. Figure 9.2 and Figure 9.3 show the average % of observed vehicles by weight bin for Interstate and US routes, respectively. Figure 9.3 and Figure 9.4 show the % of observed vehicles in different weight bins for NC and Secondary route, respectively. For comparison, Figure 9.1 shows the FHWA default WIM distribution that was included with the FHWA HCAS tool. For Interstate and US routes, we have considered the NCDOT provided data as (relatively) representative samples. The cost allocation results for NC and SR using the NCDOT WIM distribution showed large deviation from the results found using the FHWA distribution. This can be attributed to the low number of samples for NC and SR from which the WIM distributions were prepared. Therefore, in this study we have followed the NCDOT's WIM data for Interstate and US routes (Figure 9.2 and Figure 9.3), and FHWA's default distribution for the other highway routes (Figure 9.1).

The NCDOT data did not include operating weights by axle type and vehicle class. Therefore, the default axle weight distribution from the FHWA HCAS tool is used instead.

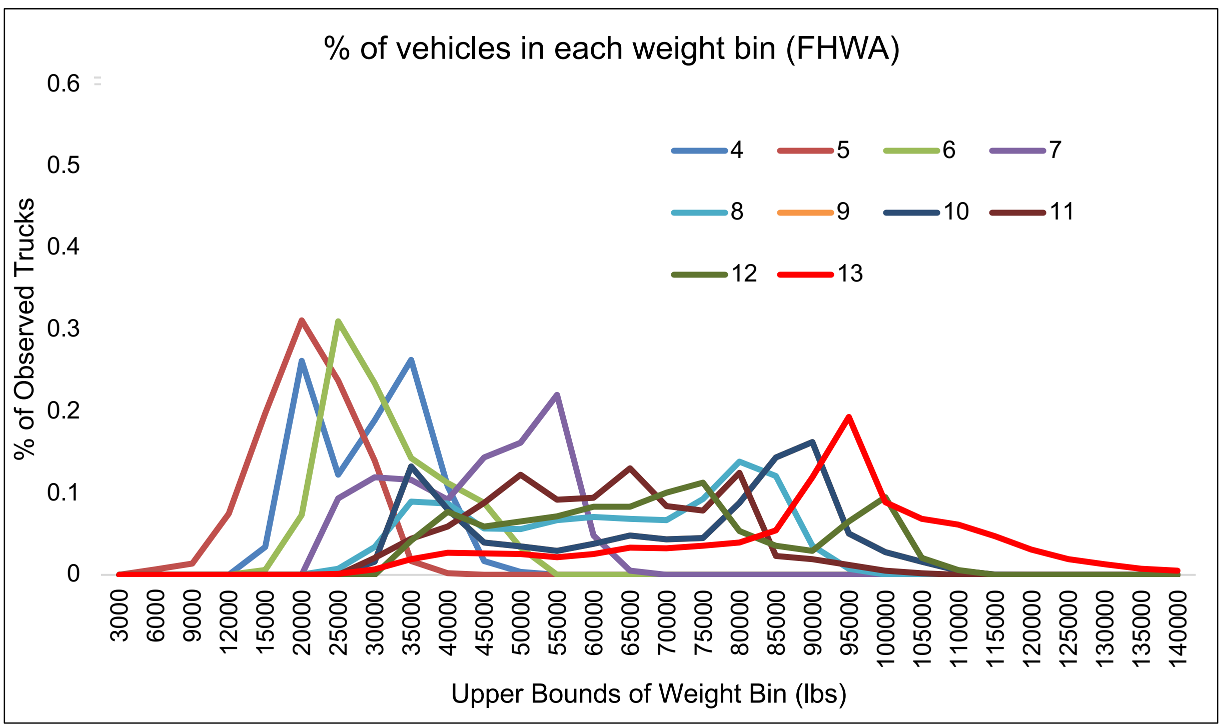


Figure 9.1: Default Operating Gross Weight Distributions for Trucks, All Routes (Source: FHWA HCAS Tool).

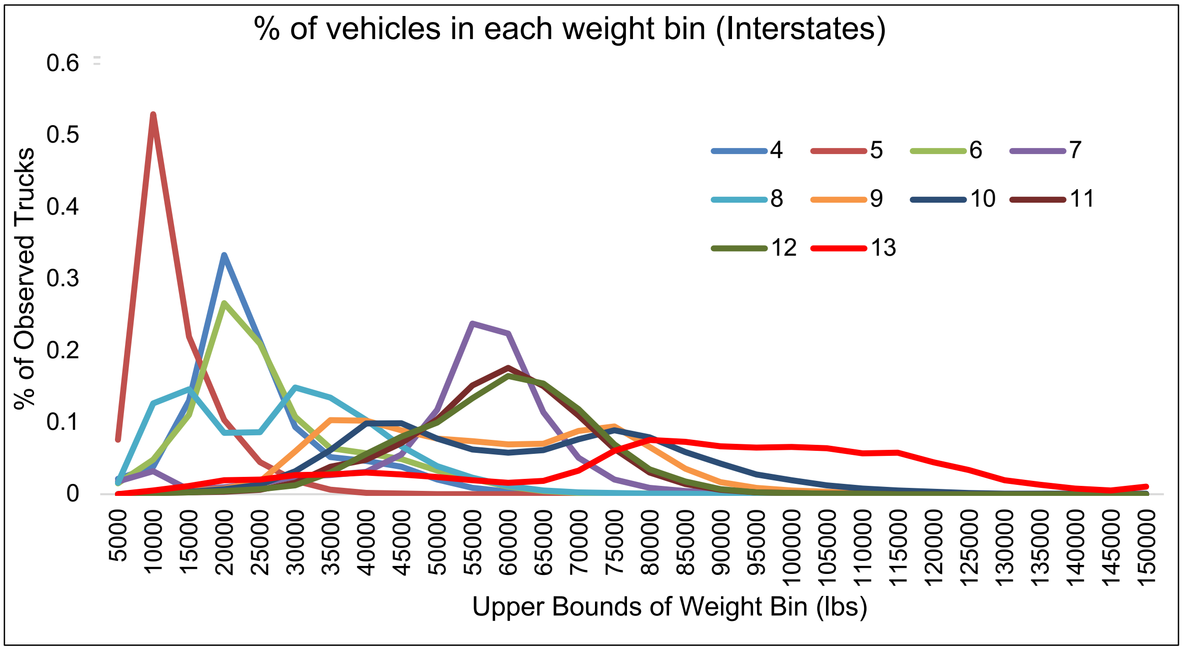


Figure 9.2: Average Operating Gross Weight Distributions of Trucks on Interstate Routes (Source: NCDOT WIM Data).

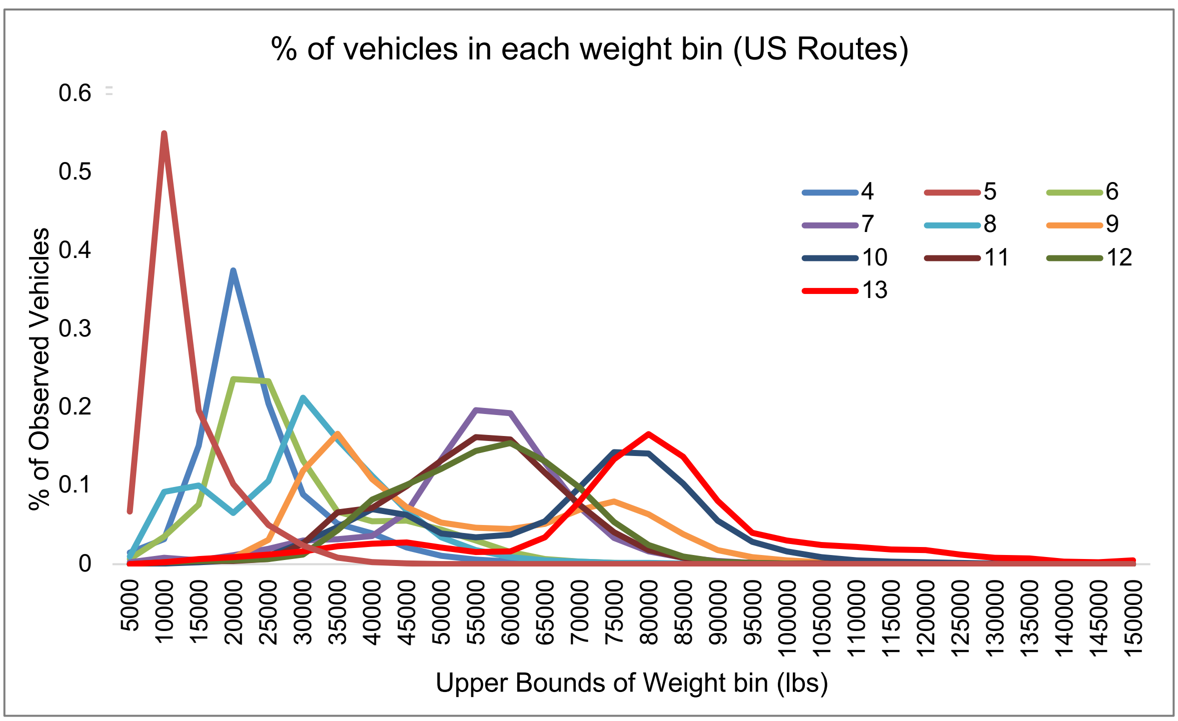


Figure 9.3: Average Operating Gross Weight Distributions of Trucks on US Routes (Source: NCDOT WIM Data).

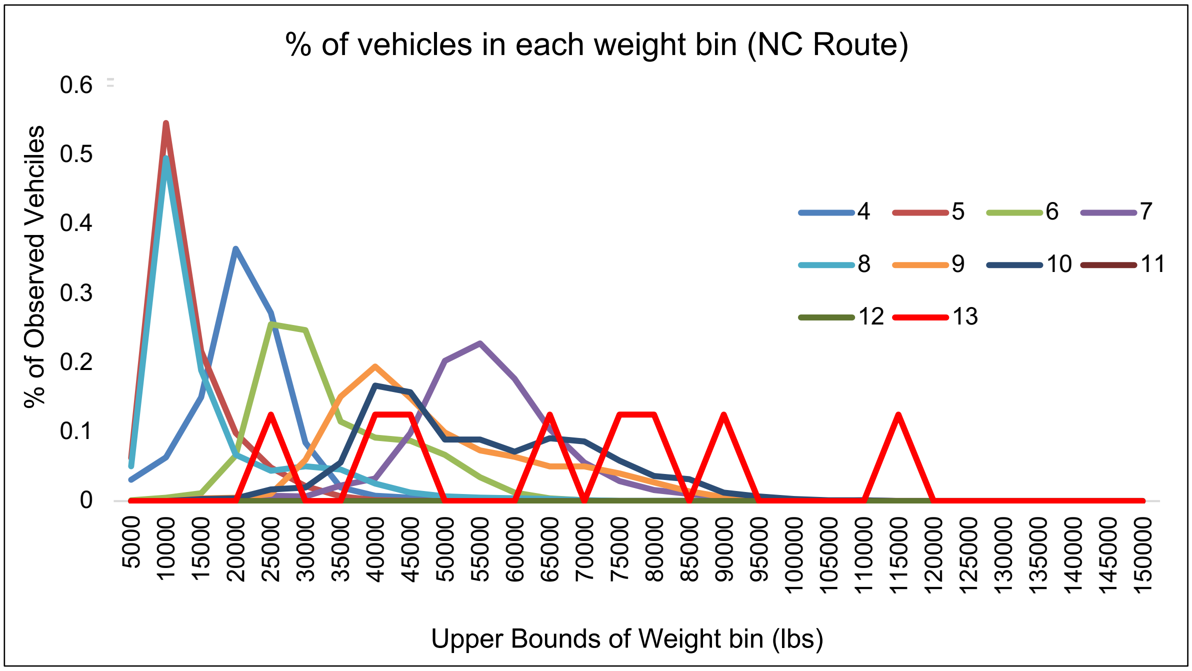


Figure 9.4: Operating Gross Weight Distributions of Trucks on NC Route (Source: NCDOT WIM Data).

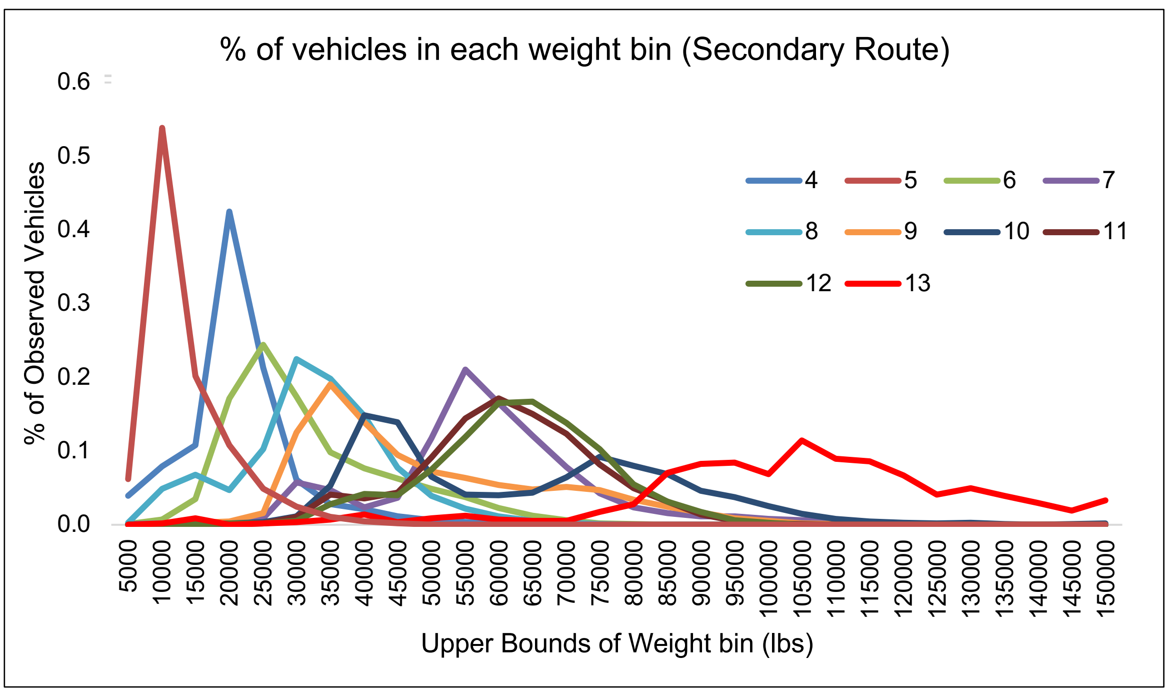


Figure 9.5: Operating Gross Weight Distributions of Trucks on Secondary Route (Source: NCDOT WIM Data).

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